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THE UNIVERSITY OF ALBERTA

THE EFFECTS OF VARIOUS THERMAL ENVIRONMENTS ON

SELECTED PHYSIOLOGICAL VARIABLES

by

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The undersigned certify that they have read, and recommend to
the Faculty of Graduate Studies for acceptance, a thesis entitled
"The Effects of Various Thermal Environments on Selected Physiological
Variables," by Denis Loiselle in partial fulfilment of the requirements
for the degree of Master of Science.

ABSTRACT

In order to determine the effect which various thermal conditions have on work performance, twelve adult male subjects were tested four times each at either a high or low humidity condition and a high, medium, or low work load in temperatures ranging from 25° - 29°C. Work load was provided by a bicycle ergometer; thermal conditions were provided by an environmental chamber.

Heart rate was recorded by an electrocardiograph, internal temperature was measured by an oesophageal. thermistor, and surface temperatures were measured by thermocouples.

The heart rate data were analyzed by an analysis of variance. The internal and surface temperature data were analyzed by analyses of variance for difference scores. Statistical techniques were employed to test for the trends of, as well as the differences among, the treatment group means.

The results showed that all three physiological parameters were affected by temperature, both heart rate and internal temperature were affected by work load, while only surface temperature was affected by humidity. The only interaction effect present was that due to ambient temperature and relative humidity on average súrface temperature.

It was concluded that bicycle ergometer work performance of brief duration was unaffected by thermal conditions ranging from 25° to 29°C and 50 per cent to 80 per cent relative humidity.

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CHAPTER I

STATEMENT OF THE PROBLEM

I. INTRODUCTION

It is well accepted that performance during tests of cardiores-
piratory fitness may be influenced by a number of factors both intrinsic
and extrinsic to the performer (52). Two such extrinsic factors are the
temperature and humidity of the ambient air. Although the influence of
these factors, particularly the former, is conceded to be of considerable
import (hence the standardization of thermal conditions in most experi-
ments) few studies have examined fitness test performance under varying
conditions of temperature and humidity and none, with the possible
exception of Suggs' and Splinter's work with one subject (51), have
quantitatively examined the combined effects of temperature and humidity
variation.

Respiratory responses show little variation under different
thermal conditions (11,12,13,35,52,56) and may thus be reasonably
excluded from consideration. Brouha et al. (13:140) found oxygen con-
sumption to be unchanged from normal to warm-dry or warm-humid conditions
and suggested that ". . .the cardiovascular reactions expressed as heart
rate or cardiac cost or cardiac efficiency. . .can accurately differen-
tiate the effects of environmental conditions." Since several tests of
cardiovascular fitness are based on the heart rate response to a given
work load (5,6,64), a knowledge of the effect which thermal conditions

have upon heart rate is an important prerequisite to cardiovascular

fitness testing in the field situation.

II. THE PROBLEM

The purpose of this thesis was to examine the relationship

between thermal environmental conditions and physical work performance.

The thermal conditions examined were delimited to various temperatures

and humidities falling in the upper range of those normally encountered

in everyday life. For reasons already given, inferences regarding car-

diorespiratory fitness test performance were drawn from a cardiovascular

response only.

III. SUB-PROBLEMS

This thesis further proposed to test the assumed (5,6,51) linear

relationship underlying the heart rate response to work load, and deter-

mine surface temperature differences between exercising and non-exercising

body parts.

IV. DEFINITIONS

1. Internal temperature: the temperature, in ^{o}C, as measured by a

thermistor ingested into the oesophagus to the level of the bifurcation

of the trachea.

2. Surface temperature: the temperature, in ^{o}C, as measured by

copper-constantan thermocouples applied with tape to the skin.

3. Average surface temperature: the surface temperature, in ^{o}C,

averaged from non-exercising body parts as distinct from upper leg

surface temperature.

        4.   Environmental temperature: the dry-bulb temperature, in ^{o}C, of the ambient air.

        5.   Environmental humidity: the relative humidity, in per cent, of the ambient air.

        6. Work load: the work, measured in kilopond meters per minute (kpm/min.), performed in pedalling a bicycle ergometer against a fixed resistance.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

In man, homoeothermy is achieved by two avenues of control:
regulation of heat gain and regulation of heat loss. Each is mediated
by two autonomic responses, vasoconstriction and shivering and vaso-
dilatation and sweating respectively. In the "basal" state with
relative humidity 40-50 per cent, shivering occurs below about $28^{\circ}C$ (30,
32) and vasodilatation below (with sweating above) about $30^{\circ}C$ (14,31,
32,33). Thus, for "basal" conditions three thermal zones can be
approximately delimited: a zone of metabolic heating below $28^{\circ}C$, a zone
of sudomotor and vasomotor cooling above $30^{\circ}C$, and a "neutral" zone of
pure vasomotor control (14,31) from $28-30^{\circ}C$.

In ambient temperatures above the "neutral" zone body heat is
excreted primarily by evaporation of sweat and direct radiation through
the skin (18,25). The latter phenomenon is preceded by vasodilatation
and consequently tachycardia (38,56). Also required in this process is
a rise in deep body temperature in order to maintain a core-to-surface
temperature gradient (38). When ambient temperature exceeds skin
temperature, that is, at $35-36^{\circ}C$ (8,14,32,33,38), radiative heat loss
is terminated (32) and the sole avenue of heat loss becomes evapora-
tion (10,32).

Exercise tends to compound the stresses of temperature and humi-
dity because of its contribution to internal temperature (42) and its

demand upon the cardiovascular system (7,11,32). Exercise does however facilitate convective heat loss by decreasing the insulative value of air in contact with the skin (33,58).

Exercise Heart Rate Variation with Ambient Temperature

Since the cardiovascular system is intimately involved with regulatory adjustments both to temperature and exercise, variation in the exercise level of cardiovascular parameters under different thermal conditions is to be expected. Williams et al. (56) are of the opinion that the only circulatory parameter significantly affected by temperature variation is sub-maximal exercise heart rate. No generally applicable quantification of the relationship between temperature and heart rate has been advanced, although there is unanimous (2,11,12,13,20,38, 51,56) agreement that exercise heart rate is a direct function of ambient temperature. This unanimity refers only to lengthy exercise periods, since Brouha et al. (12) found no significant difference in heart rates after five minutes light exercise in different thermal environments, while Dill (19) suggested that high temperatures may aid rather than hinder performance of brief severe exercise. Some idea of the duration of exercise required to yield significantly higher heart rates when performed in the heat can be gained by comparing the work of Brouha et al., above, with that of Zahar (64) who noted that the heart rate responses of adolescent boys to eighteen minutes of exercise appeared to be closely related to room temperatures.

It is unfortunate that none of the studies (1,39,53,54,55) dealing with heart rate response to varying swimming pool temperatures reported

exercise heart rates, since swimming presents a unique problem in thermoregulation. However, it is clear that ambient temperature affects exercise heart rate although it is uncertain whether the effect is noticeable during exercise of short duration.

Heart Rate Variation with Humidity

Relative humidity variation may be expected to affect cardio-vascular function indirectly, through its effect on evaporative heat loss. However, few studies have examined the effect on heart rate of humidity variation *per se*. In studies in which corrected effective temperature (see Appendix I), henceforth CET, was chosen as the ambient thermal index, the effects of humidity were confounded with those of temperature. Comparing the few relevant studies is difficult because of the methodo-logical differences among them. Hall (29) studied resting, clothed subjects and found the increase in heart rate to be less at 20 mm than at 10 mm of mercury vapor pressure. Suggs and Splinter (51), studying one subject, also found the first order effect of humidity to be negative, although not significantly different from zero. Adolph and Molnar (2) studied men outdoors under different climatic conditions and found no humidity effect on heart rate in either resting or exercising conditions.

Despite the apparent disagreement among researchers in this area, it is possible that a study conducted under controlled thermal condi-tions, employing exercise, and involving a large sample may demonstrate a positive effect of humidity on heart rate, due to the relationship between relative humidity and evaporative heat loss.

Measurement of Internal Body Temperature

Four distinct indices of internal body temperature have been employed by experimenters: tympanic membrane temperature, oral temperature, oesophageal temperature and rectal temperature. Ignoring arguments regarding efficacy of measurement, there is general agreement (3,40, 43) that oesophageal temperature yields the most sensitive record of thermal changes in the central blood. Minard et al. (40) found rectal, tympanic membrane and oesophageal (43 cm. from incisors) temperatures very similar at low work loads. However, as the work load was increased the disparity between readings increased, with rectal and tympanic membrane recordings showing a considerable response lag. Aikas et al. (3) corroborated the rectal-oesophageal (45 cm. from nostril) temperature differences and attributed them to the higher heat production and capacity, better insulation, and poorer circulation of the pelvis as compared with the oesophagus. Nielsen and Nielsen (43) found rectal temperature more variable than oesophageal (45-50 cm. from nostril) temperature during bicycle ergometer exercise with the arms. When the legs were employed, oesophageal temperature rose faster, reached a lower level, and fell more quickly during recovery than did rectal temperature. There is thus little doubt that deep oesophageal temperature is a satisfactory measure of internal body temperature.

Internal Temperature Variation with Work Load

Because muscles, considered mechanically, are highly inefficient (51), exercise greatly accelerates heat production. It follows that heat production is dependent on the magnitude of exercise. To this end,

many studies (3,37,38,47,58,61,62,63) have supported Nielsen's finding

(42) that rectal temperature is directly proportional to the work load.

Aikas et al. (3) have recently demonstrated that this relationship holds

equally well for deep oesophageal temperature. There is general agree-

ment, however, that the proportionality holds only up to certain tempera-

tures, variously reported as: $26^{\circ}C$ in water (39), $26^{\circ}CET$ (38), $27.5^{\circ}CET$ (37),

$29^{\circ}CET$ (47) and $31^{\circ}C$ saturated (61).

Internal Temperature Variation with Ambient Temperature

As evidenced by the above remarks, Nielsen's conclusion (42)

that exercise rectal temperature is unrelated to ambient temperature, in

dry-bulb ranges from $5^{\circ}-35^{\circ}C$, seems no longer tenable, although he and a

co-worker recently advanced further evidence (43) in support of this

claim. Possibly the strongest evidence against Nielsen's claim is

supplied by Adee's finding (1) that the correlation between rectal and

swimming pool water temperatures increased from $r = 0.64$ to $r = 0.90$

when the exercise was increased from a 50-yard sprint to a 1,500 meter

race. This suggests that the relationship between rectal and ambient

temperatures increased with work to approach linearity in severe exer-

cise. However, this result is difficult to interpret because of the water

environment and the vast difference in duration of the two exercise con-

ditions.

Additional evidence for the refutation of Nielsen's stand is

available. Bernauer (8) found a significant difference among rectal

temperatures after a 10-minute treadmill run in five ambient tempera-

tures from $10^{\circ}-32.5^{\circ}CET$. Edholm et al. (20) reported the internal

temperature response (measured by a rectal probe) to prolonged heavy work to be roughly twice as great at 35.5°C as at 10°C. Brouha et al. (12) found the internal temperature response (measured orally) to five minutes light bicycle ergometer exercise (360 and 540 kgm/min. for a woman and man respectively) to be non-significant at the 22.4°C but significant at 32.5°C. Similarly, Brouha et al. (13) found that recovery oral temperatures did not differ significantly below 27°CET whereas they did above this temperature. Consolazio et al. (17) concluded that ambient temperature influenced rectal temperature above 30°C for all levels of activity from rest to fairly severe. There thus seems little doubt that (at least high) ambient temperatures have some effect on internal temperature during exercise.

Internal Temperature Variation with Humidity

Humidity may be expected to influence internal temperature in much the same manner as suggested for cardiovascular function, that is, through its effect on heat loss. Pertinent literature is scarce. In 1931, Houghton, referred to by Nielsen (42), found rectal temperature to be unrelated to relative humidity within the range 20-95 per cent. Experiments were conducted at temperatures from 10°-20°C and a work load of 80 kgm/min. Nielsen's study of 1938 (42) substantiated these findings and extended the temperature range by 5° and 15° on the lower and upper boundaries respectively. Hall's evidence (29) of a temperature by humidity interaction effect on rectal temperature must be interpreted cautiously because of the extreme conditions involved, that is, subjects at rest, in temperatures up to 71°C.

Measurement of Surface Temperature

It has been known for some time that the increased thermogenesis in exercising muscles (4) is rapidly reflected in increased surface temperature over those muscles. As early as 1935 Lewis and Pickering (36) demonstrated a $2^{\circ}-3^{\circ}$ increase in surface temperature over voluntarily exercised hypothenar muscles. This temperature rise occurred within ten minutes. Several years later Grant (26), and Grant and Pearson (27) received similar but more dramatic results from measurements over exercising forearm and anterior tibial regions. They showed that even very mild exercise caused surface temperatures to rise whereas rates of $1^{\circ}C/min.$ for five minutes were achievable with more intense exercise. This rise in skin temperature they attributed to increased conductance brought about by an increased blood supply to the muscle, rather than cutaneous vasodilatation. More recently Cooper et al. (18), employing more refined techniques, demonstrated surface temperature increments of similar magnitude but attributed them to a somewhat different cause. They argued that the surface temperature increments were too rapid to be brought about by the conduction of heat from muscle to skin. They concluded that heat was transferred by convection from the muscle vertically, with the assistance of a "muscular pump," via cutaneous venous plexuses to the skin.

Regardless of the mechanisms involved, it is apparent that the temperature of the surface is increased over exercising muscles.

Average Surface Temperature Variations with Work Load

Since skin temperature is a product of both the rate of heat loss and the rate of cutaneous blood flow and since the experimental conditions

employed by various researchers were not identical, no conclusions re-
garding the relationship between work load and skin temperature is forth-
coming.

Grant and Pearson (27) found surface temperatures to vary with
the severity of the exercise. However, the exercise involved was
extremely localized. Winslow and Gagge (58) concluded from a study of
two subjects performing on a bicycle ergometer that average surface
temperature (mean of 15 points) increased with increasing work until
the work load became severe, at which point it decreased. They also
noted that surface temperatures tended to be higher during rest than
work, particularly in warm environments. In contradiction to these
findings, Robinson et al. (47) found the surface temperatures of two
subjects engaged in treadmill walking to decrease slightly with in-
creasing work load.

Average Surface Temperature Variation with Ambient Temperature

There is general agreement (15,25,60) that surface temperatures
during resting conditions are highest over the head, intermediate over
the trunk, and lowest over the extremities. There is considerably less
agreement as to how these measures are affected by ambient temperature
and exercise.

The findings of Robinson et al. (47) contradict those of Winslow
and Gagge (58) but comparison is limited by the different kinds of
exercise imposed (cycling versus grade walking respectively), the
different work durations involved (50 minutes discontinuous versus 90
minutes continuous respectively), and the small number of subjects

studied (two in each case). Hence Winslow and Gagge claimed that exercise surface temperature bore no relationship to air temperature above 32°C while Robinson et al. found it to increase with room temperature, in the range studied (17°-40°C). In support of Robinson's findings, Bernauer (8), in a study of seven subjects engaged in an all-out treadmill run demonstrated a highly linear relationship between surface and ambient temperatures when the latter was varied from 10°-32.5°CET.

Average Surface Temperature Variation with Humidity

The temperature of the skin's surface depends in part on the rate of evaporative heat loss which in turn depends on the vapor pressure differential between skin and air (59). It is thus not unreasonable to assume that ambient humidity influences surface temperature. However, this problem has apparently received no experimental consideration as regards exercising subjects. Winslow et al. (59) observed that the skin blood flow of resting subjects was greater, for any given temperature, at high relative humidities. Inasmuch as exercise tends to compound thermoregulatory responses seen at rest, this observation tends to support the above assumption.

Hypotheses

From the above review of literature, it is hypothesized that:

1. heart rate varies directly with temperature, humidity and work load;

2. internal temperature varies directly with temperature, humidity and work load;

3. surface temperature varies directly with humidity;

4. surface temperature is highest over exercising muscles; and

5. high temperature and high humidity in combination have a greater effect than does either separately.

CHAPTER III

METHODS AND PROCEDURES

Independent Variables

Three factors were investigated: work load, ambient tempera-
ture, and relative humidity. Systematic variation of the latter two
was achieved by conducting all experiments in the Environmental Chamber
of the Department of Physiology. Dry- and wet-bulb temperatures were
controlled separately to within $0.5^{\circ}C$. Chamber temperatures were
monitored continuously.

Work load was systematically varied by employing a Monark bicycle
ergometer. Although the success of the study was unrelated to the
absolute accuracy of the work loads, the ergometer was calibrated prior
to use. Calibration was effected by suspending known weights from the
fulcrum of the movable pendulum and adjusting the zero point scale
until correspondence was achieved.

The three factors (temperature, relative humidity, and work load)
were studied at four, two, and three levels respectively. These levels
were 25°, 29°, 33°, and $37^{\circ}C$, 50 and 80 per cent, and 450, 750, and
1,050 kpm/min. The duration of exercise was six minutes.

Dependent Variables

Three physiological parameters were studied: heart rate, internal
temperature and surface temperature. All parameters were recorded on a
Beckman five-channel Type R/B Dynograph pen recorder. Prior to

experimentation, paper speed was calculated (by use of the recorder's

one-second timer) to be 2.508 cm./sec. The resulting error (0.008 cm./

sec.) was judged negligible for the purpose of heart rate recording.

Heart rate was measured by determining the time required for 30

R-waves of the electrocardiograph (ECG). The electrodes of the ECG were

smeared with electrolytic paste and applied (two on the ventral and one

on the dorsal surface)at the level of the infra-pectoral sulci with an

elastic strap.

Oesophageal temperature was recorded as an indicator of deep body

temperature. A probe consisting of a polyvinyl tube containing a

thermistor was ingested so that the thermistor lay 43 cm. from the

incisors. The gain of the amplifier was adjusted such that a 1 cm.

deflection of the recording pen corresponded to $1^{o}C$ giving a range from

$35^{o}-40^{o}C$. Accuracy of the mid-scale balance was checked twice a day

by immersing the probe in water at $37.5^{o}C$.

Surface temperature measurements were made with thermocouples

consisting of #28 gauge copper and constantan (Cu-Co) wires overlapped

1 mm. and joined with silver solder. The resulting 1.5 to 2 cm. loop

was insulated by immersion in, and slow withdrawal from, Inselex E33

Varnish diluted with Inselex Varnish Thinner. Thermocouples were

applied to the surface, after cleaning the area involved with a 70 per

cent alcohol solution, with a 1 cm. X 2 cm. length of masking tape

placed over the thermosensitive junction. Surface temperature readings

were made from the abdomen (one inch above the navel), chest (over the

xyphoid process of the sternum), forehead, back (over both scapulae at

the level of their inferior angles), upper right arm (on the lateral

aspect over the insertion of deltoid muscle) and upper right leg (over rectus femoris midway along the thigh).

Outputs from the seven locations were fed into a switch box which enabled recordings to be made from each location separately or from the average of the first six locations. The thermocouples were wired in series with a reference thermocouple held at $0^{\circ}C$ in ice water. Surface temperatures were recorded on a single channel such that a deflection of 1 cm. corresponded to $2^{\circ}C$ over a range from $30^{\circ}-40^{\circ}C$.

Experimental Design

A split-plot design for a "three factor experiment with repeated measures" (71:337) was employed. Subjects were nested within the work load and humidity factors and repeatedly measured over the level of the temperature factor. Thus humidity-work load combinations were randomly assigned between subjects whereas temperature levels were randomly assigned within subjects. Each nested factor combination was replicated twice. Thus a total of twelve subjects were tested four times each. The experimental design is diagrammatically represented below and in Appendices II and III.

Diagrammatic Representation of the Experimental Design

|		Subject	25°	29°	33°	39°
	50%	1				
450 kpm		2				
	80%	3				
		4				
	50%	5				
750 kpm		6				
	80%	7				
		8				
	50%	9				
1050 kpm		10				
	80%	11				
		12				

Subjects

Eleven Physical Education graduate students and one staff member (all volunteers) were non-randomly selected. All were familiar with the purpose of the experiment and had had considerable experience riding a bicycle ergometer. None had previously ingested an oesophageal temperature probe. The physical characteristics of the subjects are listed in Appendix II, Table I.

Experimental Protocol

Subjects reported to a room adjacent to the chamber immediately before the trial. The temperature of this room was maintained at 24°C. Here the subject changed into shorts and shoes (optional). The subject was seated on a stool, the ECG electrodes and thermocouples attached in place, and heart rate prior to ingestion of the thermistor was recorded. Ingestion of the thermistor was aided by sipping water. For some subjects (two) a three per cent solution of xylocaine was sprayed onto the back of the oral cavity in order to suppress the gag reflex. Immediately after successful ingestion heart rate was again recorded. (These recordings will henceforth be referred to as pre- and post-thermistor heart rates.) Pre-exercise levels of all parameters were then recorded and the subject admitted to the environmental chamber.

Within the chamber, the height of the ergometer seat was adjusted to the subject's satisfaction and an electronic metronome (set at 100 beats/min.) activated. At a signal from the experimenter, who remained in the anteroom with the recorder throughout, the subject commenced pedalling. When the pedalling rate reached the required 50 rev./min. an

assistant, who remained in the chamber throughout, increased the tension

on the friction belt until the work load was at the required level. It

was necessary for the assistant to adjust the tension throughout the six-

minute exercise period in order to maintain a constant work load.

Exercise levels of all parameters were recorded from the fifth to the

sixth minute of exercise. Surface temperatures were recorded twice

from each point in the order: left scapulae, upper arm, chest, forehead,

right scapulae, abdomen, upper leg and average. The final two measure-

ments fell within the last 5-10 seconds of exercise.

With one exception (see Appendix II), subjects were tested every

second day for seven days. As a much greater length of time was

required to heat than to cool the chamber, testing periods (that is, time

of day) could be neither standardized nor randomized. It was thus

necessary to test the cooler conditions early and the hot conditions

late in the day. All experimentation was completed between May 31st

and June 9th, 1966. Thus none of the subjects was previously acclima-

tized to heat or cold. Testing order and periods are given in Appendix

II, Table II.

The subjects were not informed about the thermal conditions under

which they performed until after their final trials.

Statistical Analyses

In order to determine the effect of thermistor ingestion on

resting heart rate, the pre- and post-thermistor heart rates were

considered as two levels of a treatment factor and the data analyzed by

an analysis of variance for a 4 (days) x 2 (condition) factorial design

with randomized blocks (27:213).

Since the results of a pilot study (involving boys aged 12-14 years) showed that exercise heart rates were not significantly affected by an "anxiety-producing" situation which included ingestion of a thermistor, exercise heart rate data were subjected to an analysis of variance (rather than a co-variance analysis) to determine the main and interaction effects of the independent variables. Trend analyses were performed on the temperature and work load main effects. The significance of differences among the temperature conditions was assessed by means of Duncan's New Multiple Range Test (27:136).

An analysis of variance for difference scores (27:295) was used to evaluate the changes in oesophageal, mean surface, and upper leg surface temperatures brought about by exercise. Trend analyses and range tests were performed as outlined above. Differences between average and upper leg surface temperatures were similarly assessed.

When significant, interaction effects were assessed for trend and plotted graphically.

Null hypotheses were rejected at the 95 per cent level of confidence.

Limitations of the Experimental Design

1. Nesting of factors within subjects decreased the power of tests of significance on those factors.

2. Power was further reduced by the small number of replications.

3. Tests of trend were performed on only three or four points.

4. A possible period effect on heart rate due to food intake (20)

was uncontrolled. A similar possibility regarding oesophageal tempera-
ture (42,47) and surface temperature (20) was overcome by working with
difference scores.

5. The repeated measures nature of the design involved the
possibility of carry-over effects and consequent violation of the assump-
tion of homogeneous variance-covariance matrices (29,34).

6. Because the experimental design involved a fixed effects
model of the analysis of variance, generalization to other treatment
conditions was rendered statistically indefensible (27:301).

7. Similarly, since subjects were non-randomly selected,
generality of the results was vastly reduced (28:7).

Methodological Limitations

1. Mean surface temperature was averaged from only six points.

2. No other index of skin blood flow (2,74) was employed.

3. Placing tape over the thermosensitive junctions probably
reduced evaporative heat loss and consequently increased the tempera-
ture of those areas.

4. Added to the above was the temperature-elevating effect of
increased pressure (59,60) caused by the tape.

5. The unequal quantities of water consumed during ingestion of
the thermistor may have affected subjects differently (13,51).

6. The effect of a localized application of xylocaine upon
systemic circulation was unknown.

Limitations of the Statistical Analyses

    1. The pilot study sample was drawn from an entirely different age-height-weight population from the experimental sample. Hence inferences from the former to the latter were questionable.

    2. The analyses of variance for difference scores assumed a slope of 1 for the within-groups regression line relating the undifferenced measures.

    3. Tests of significance in the analysis of variance of differences between mean and upper leg surface temperatures were based on uncomputable conditional probabilities.

CHAPTER IV

RESULTS

The Effect of Practice on Ergometer Work Performance

Table A, Appendix III lists the number of revolutions of the
bicycle ergometer made by each subject on each trial. Table I gives
the results of an analysis of variance performed on the data. The
analysis offered no evidence of unequal performance on successive days.

TABLE I

SUMMARY OF ANALYSIS OF VARIANCE OF WORK PERFORMANCE CHANGES WITH TRIALS

Source	SS	d.f.	M.S.	F	P
Subjects	45.42	11	4.13		
Trials	8.60	4	2.15	--	
Error	99.16	28	3.54		

The mean performances for Days One to Four respectively were
302.8, 301.7, 302.4 and 301.8 revolutions. The overall mean was
302.1 $\pm$ 1.9 revolutions compared with the performance requirement of
300 revolutions for the six minutes. The resulting error, 0.71 per cent,
was deemed experimentally insignificant.

The Effect of Thermistor-Ingestion on Non-Exercise Heart Rate

The data (Table B, Appendix III) were analyzed by an analysis of
variance for factorial design with randomized blocks. Through neglect

on the part of the experimenter, complete data for only ten subjects
were collected, hence subjects #4 and #11 were not considered in the
analysis. Table II gives the mean heart rates for each treatment con-
dition, as well as the difference in heart rates between levels of the
thermistor factor. Table III summarizes the analysis of variance.

TABLE II

MEAN HEART RATES (beats/min.) FOR TWO THERMISTOR CONDITIONS AT
EACH OF FOUR TRIALS
(n=10)

	Trial			
	1	2	3	4
Pre-Thermistor	78.3	78.2	84.6	77.4
Post-Thermistor	96.9	97.1	107.0	96.0
Difference	18.6	18.9	22.4	18.6

TABLE III

SUMMARY OF ANALYSIS OF VARIANCE OF EFFECT OF THERMISTOR
INGESTION ON NON-EXERCISE HEART RATE

Source	SS	d.f.	M.S.	F.	P
Subjects	8085.1	9	898.3		
Trials	1090.9	3	363.6	2.24	$> .05$
Thermistor	7702.8	1	7702.8	47.36	$< .005$
Trials X Thermistor	51.6	3	17.2	--	
Subjects X Trials	5175.2	27	191.7		
Subjects X Therm.	2079.1	9	231.0		
Sub.X Trials X Therm.	2993.0	27	110.9		
Error	10247.2	63	162.7		

The three subjects X conditions mean squares were tested with

Hartley's test of homogeneity of variance of separate error variance estimates (57:93) before pooling to form the error term Subjects X Treatments. The null hypothesis of no difference between pre- and post-thermistor heart rates was rejected. Although the difference between pre- and post-thermistor heart rates was quite similar over the four days, the coefficient of correlation was only moderate: $r = 0.69$. The coefficients of correlation between the length of time required to ingest the thermistor (see Table C, Appendix III) and pre- and post-thermistor heart rates were respectively $r = 0.21$ and $r = -0.73$. That is, pre-thermistor heart rate and ingestion time were largely unrelated while faster ingestion times tended to be associated with higher post-thermistor heart rates.

Changes in Pre-Exercise Heart Rates over Successive Trials

Mean ($n = 12$) pre-exercise heart rates (Table D, Appendix III) for trials one to four were 78.8, 75.3, 76.0 and 72.8 beats/min. respectively. Although there was no evidence of a difference among means, there was evidence (see Table IV) that pre-exercise heart rates decreased linearly over the four trials.

TABLE IV

SUMMARY OF ANALYSIS OF VARIANCE OF PRE-EXERCISE HEART RATE

Source	SS	d.f.	M.S.	F	P
Subjects	5216.9	11	474.3		
Trials	218.8	3	72.9	1.78	$> .10$
Trials (lin.)	180.3	1	180.3	4.41	$< .05$
Trials (quad.)	0.1	1	0.1	--	
Error	1348.3	33	40.9		

Exercise Heart Rate

The main and interaction effects of the independent variables
(henceforth T, H, and WL) on exercise heart rate are summarized in
Tables V and VI (raw data is given in Table E, Appendix III).

TABLE V

SUMMARY OF ANALYSIS OF VARIANCE OF EXERCISE HEART RATE

Source	SS	d.f.	M.S.	F	P
H	111.0	1	111.0	---	
WL	19021.9	2	9510.9	20.85	<.005
WL(lin.)	19012.5	1	19012.5	41.69	<.005
WL(quad.)	9.4	1	9.4	---	
H X WL	2637.5	2	1318.8	2.89	>.10
Error	2736.6	6	456.1		
T	692.4	3	230.8	8.20	<.005
T(lin.)	537.0	1	537.0	19.05	<.005
T(quad.)	136.7	1	136.7	4.85	<.05
T X H	160.2	3	53.4	1.90	>.10
T X WL	171.2	6	28.5	1.01	>.25
T X H X WL	207.0	6	34.5	1.23	>.25
Error	506.9	18	28.2		

Exercise heart rates were not affected by relative humidity. The
mean heart rates for the high and low relative humidity conditions were
respectively 141.4 and 144.5 beats/min.

Virtually all the variation among work load conditions was due to
the linear component of trend. It must be remembered, however, that only
three points were involved in the trend analysis and the work loads were
not severe (maximum heart rate attained = 184 beats/min.).

The significance of the quadratic trend of heart rates over
temperature must be interpreted in the light of the range test results.
Much of the quadratic component of trend was contributed by the higher

TABLE VI

SUMMARY OF DUNCAN'S NEW MULTIPLE RANGE TEST OF HEART RATE RESPONSE (beats/min.) TO AMBIENT TEMPERATURE

Levels	29°	25°	33°	37°
Means	138.9	140.4	143.6	148.8
Differences (P = .05)				

heart rate values at 33° and 37°C rather than by a significantly lower value at 29°C. The validity of this statement is demonstrated in Figure 1.
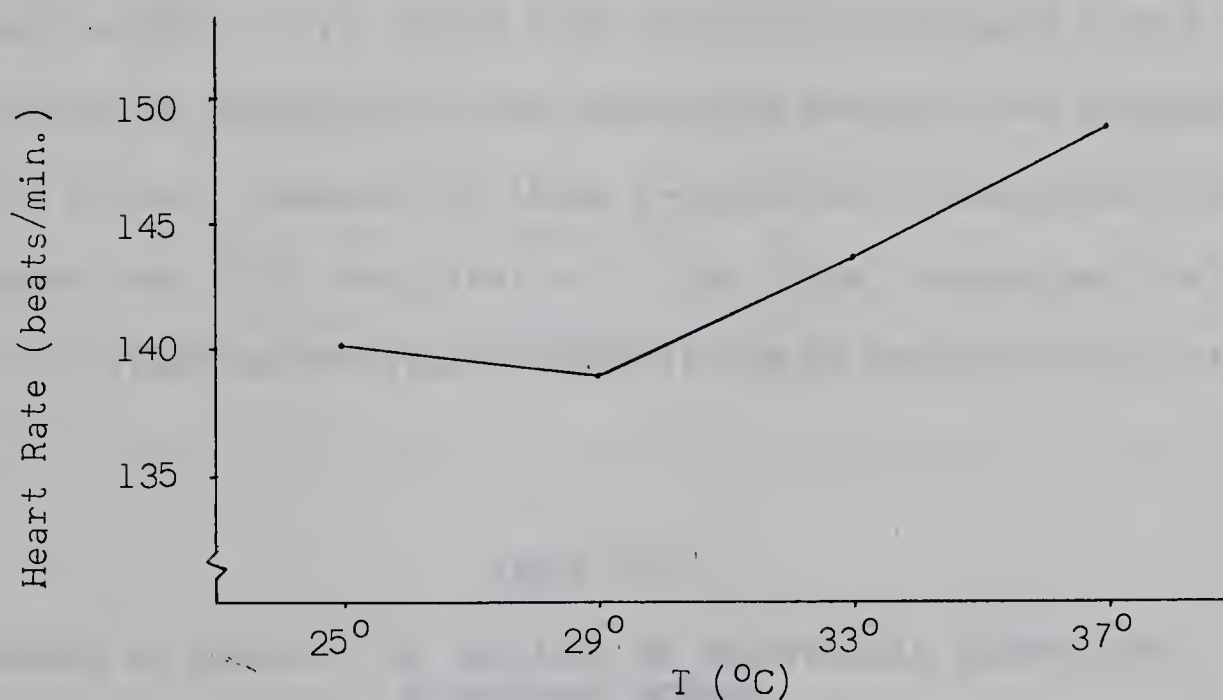
Figure 1: Mean Heart Rate Response to Ambient Temperature.

Oesophageal Temperature Changes with Exercise

The exercise datum for Subject #6 at 37°C (see Table F, Appendix III) was unrecorded due to an experimental oversight. The difference datum was estimated according to the methods of Federer (22:125). The accuracy of this estimate was unassessable (57:283). An analysis of

variance of the difference scores (exercise oesophageal temperature-pre-exercise oesophageal temperature) was performed on the completed data. The effect of the datum estimation was to reduce the degrees of freedom for the second error term by one.

The slope of the common within-groups regression line (21:290) relating pairs of undifferenced scores was calculated to be 0.62. Edwards (21:296) cautions that if this slope ". . .differs considerably from 1.00, then we can expect the estimate of experimental error based upon the analysis of variance of the [difference] measures to be considerably larger than the estimate of experimental error obtained if we use the correct slope. . . ." Since 0.62 differs considerably from 1.00, the F-ratios given in Table VII may be considered conservative estimates of their true values. However, of those F-ratios with associated probabilities greater than 0.05, only that of T X WL (2.04) approached the critical value (2.70) required for significance at the 95 per cent level of confidence.

TABLE VII

SUMMARY OF ANALYSIS OF VARIANCE OF OESOPHAGEAL TEMPERATURE
DIFFERENCE SCORES

Source	SS	d.f.	M.S.	F	P
H	0.2852	1	0.2852	2.14	$>.10$
WL	1.8854	2	0.9427	7.06	$<.05$
WL(lin.)	1.7578	1	1.7578	13.23	$<.025$
WL(quad.)	0.1267	1	0.1267	--	
H X WL	0.4254	2	0.2127	1.59	$>.25$
Error	0.8013	6	0.1336		
T	0.2106	3	0.0702	1.27	$>.25$
T(lin.)	0.1170	1	0.1170	2.12	$>.10$
T(quad.)	0.0752	1	0.0752	1.36	$>.25$
T X H	0.1707	3	0.0569	1.03	$>.25$
T X WL	0.6763	6	0.1127	2.04	$>.10$
T X H X WL	0.5662	6	0.0944	1.71	$>.10$
Error	0.9437	17	0.0551		

Figures 2 to 5 describe graphically some of the findings.
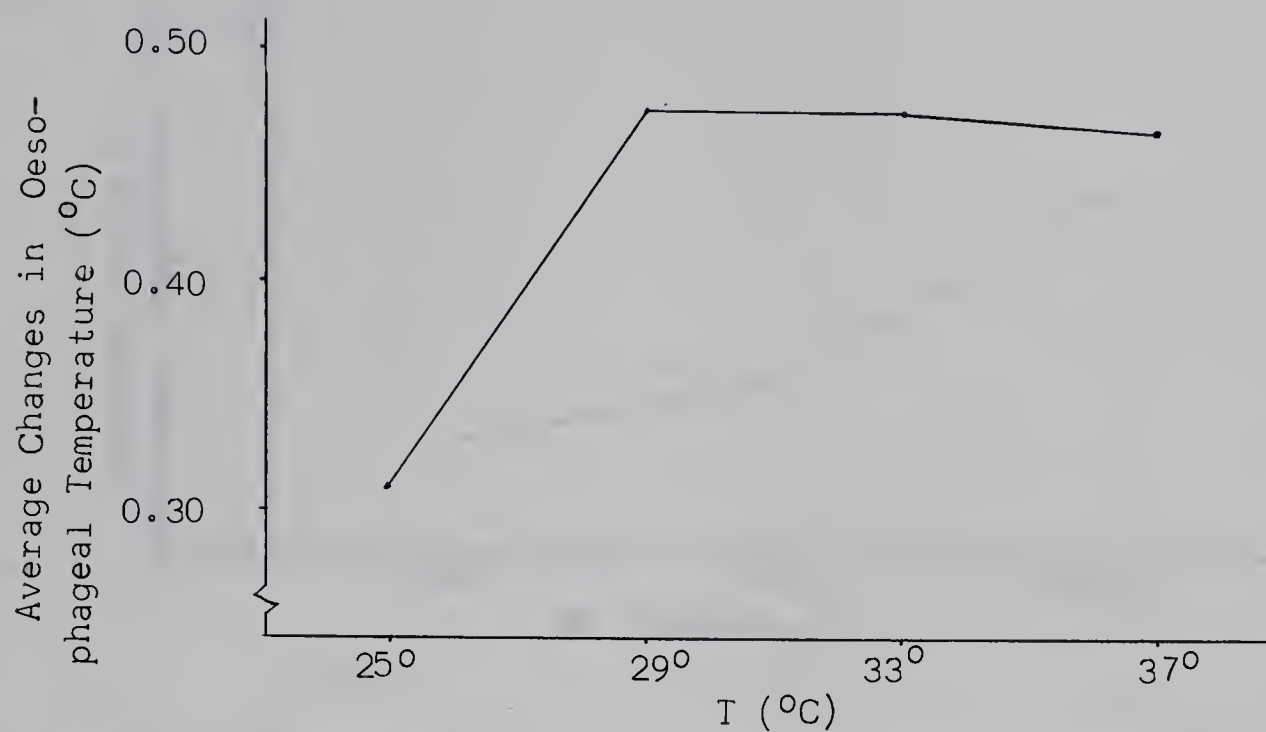
Figure 2: Oesophageal Temperature Changes with Ambient Temperature.

TABLE VIII

SUMMARY OF DUNCAN'S NEW MULTIPLE RANGE TEST OF OESOPHAGEAL
TEMPERATURE (^{o}C) CHANGES WITH AMBIENT TEMPERATURE

Levels	25°	33°	37°	29°
Means	0.31	0.46	0.46	0.47
Differences (P = .05)				
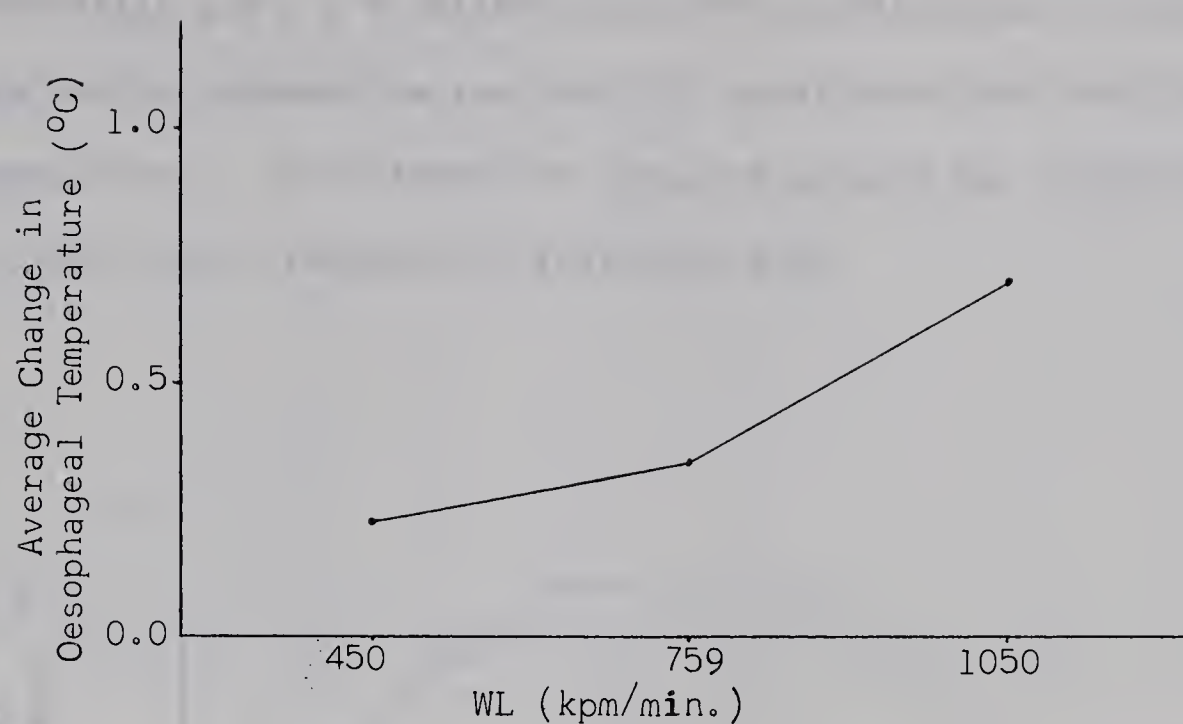
Figure 3: Oesophageal Temperature Changes with Work Load.

The F-ratio for WL was significant as was the linear component of trend which accounted for 93.23 per cent of the variance.
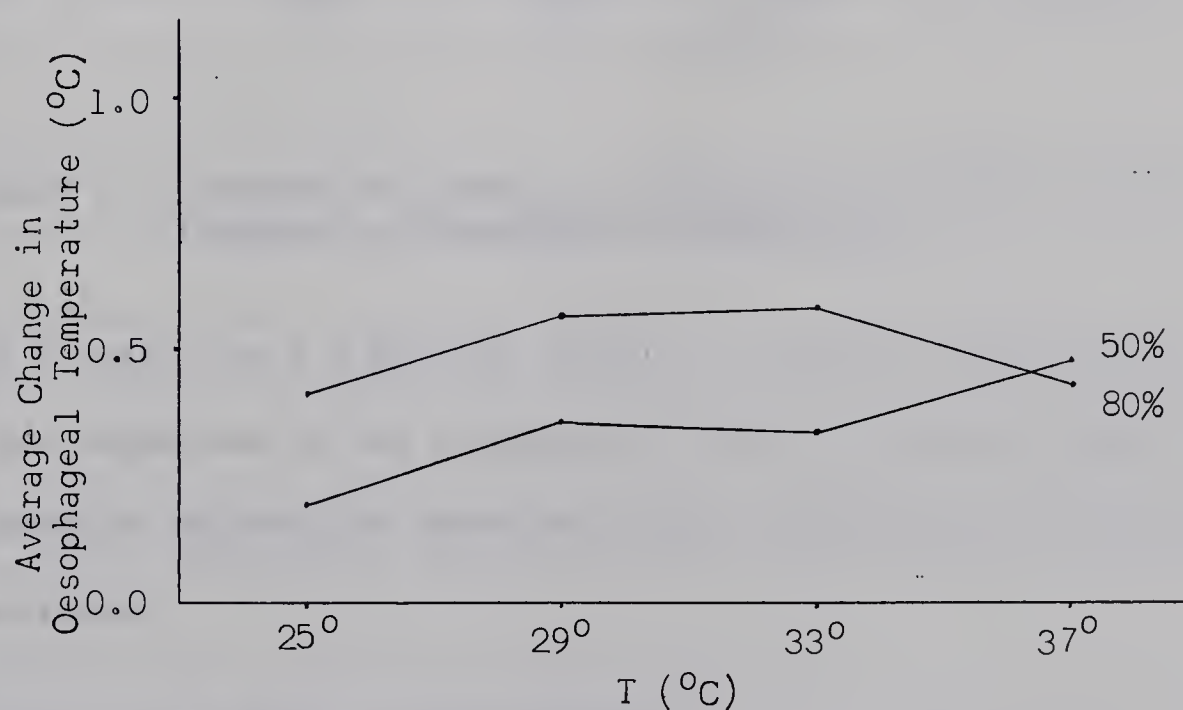
Figure 4: Interaction Effect of Temperature and Humidity on Changes in Oesophageal Temperature.

The F-ratio for T X H failed to achieve significance as attested by the parallelism between the two humidity conditions over the three lowest temperatures. The interaction variance present was contributed largely by the highest temperature (see Figure 4).
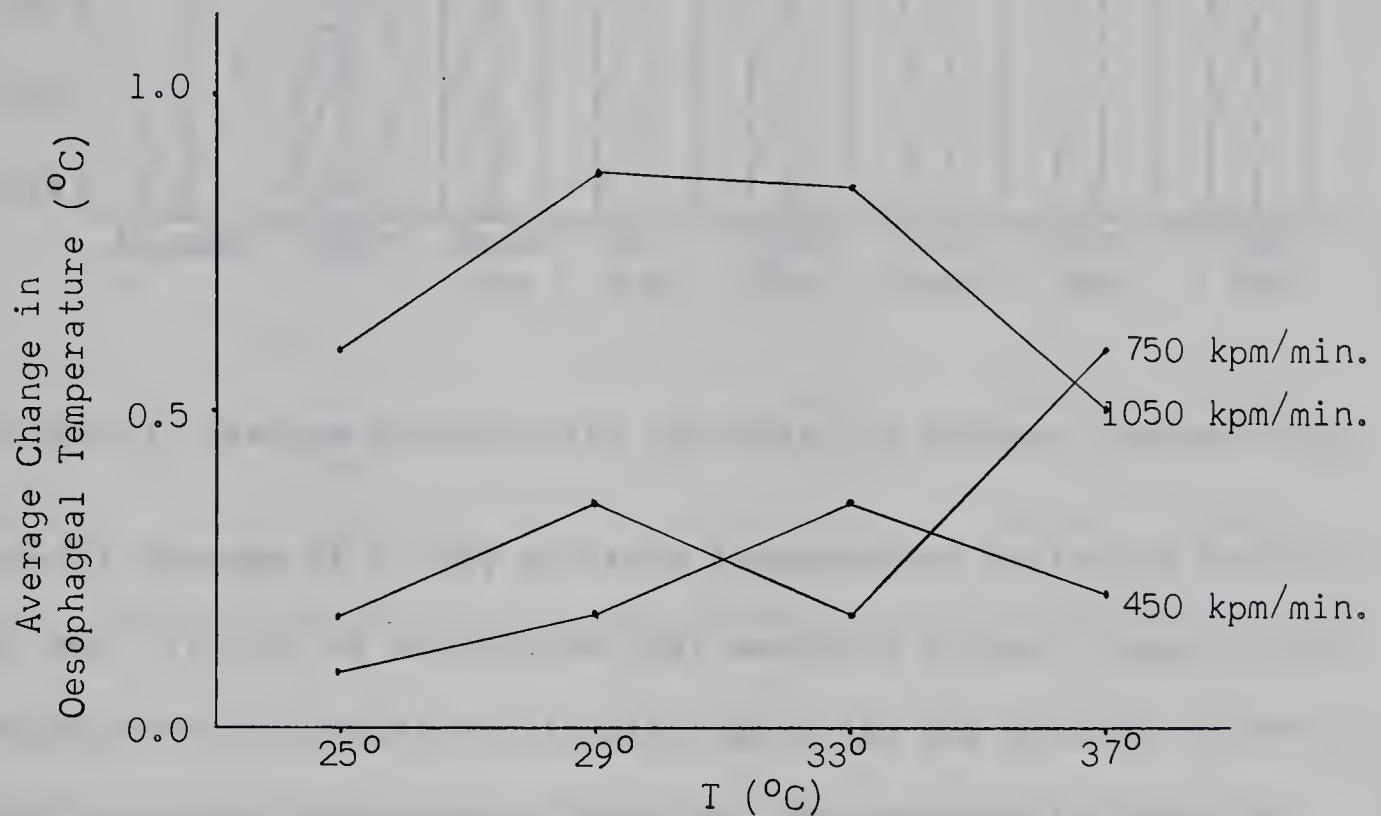
Figure 5: Interaction Effect of Temperature and Work Load on Changes in Oesophageal Temperature.

The F-ratio for T X WL also failed to achieve significance. However, the magnitude of the interaction effect is shown (Figure 5) by the considerable variability among work load conditions at the two highest temperatures.

Surface Temperature Changes with Exercise

Figure 6 shows the average (n = 48) pre-exercise and exercise surface temperatures for each of the seven points examined. Also shown
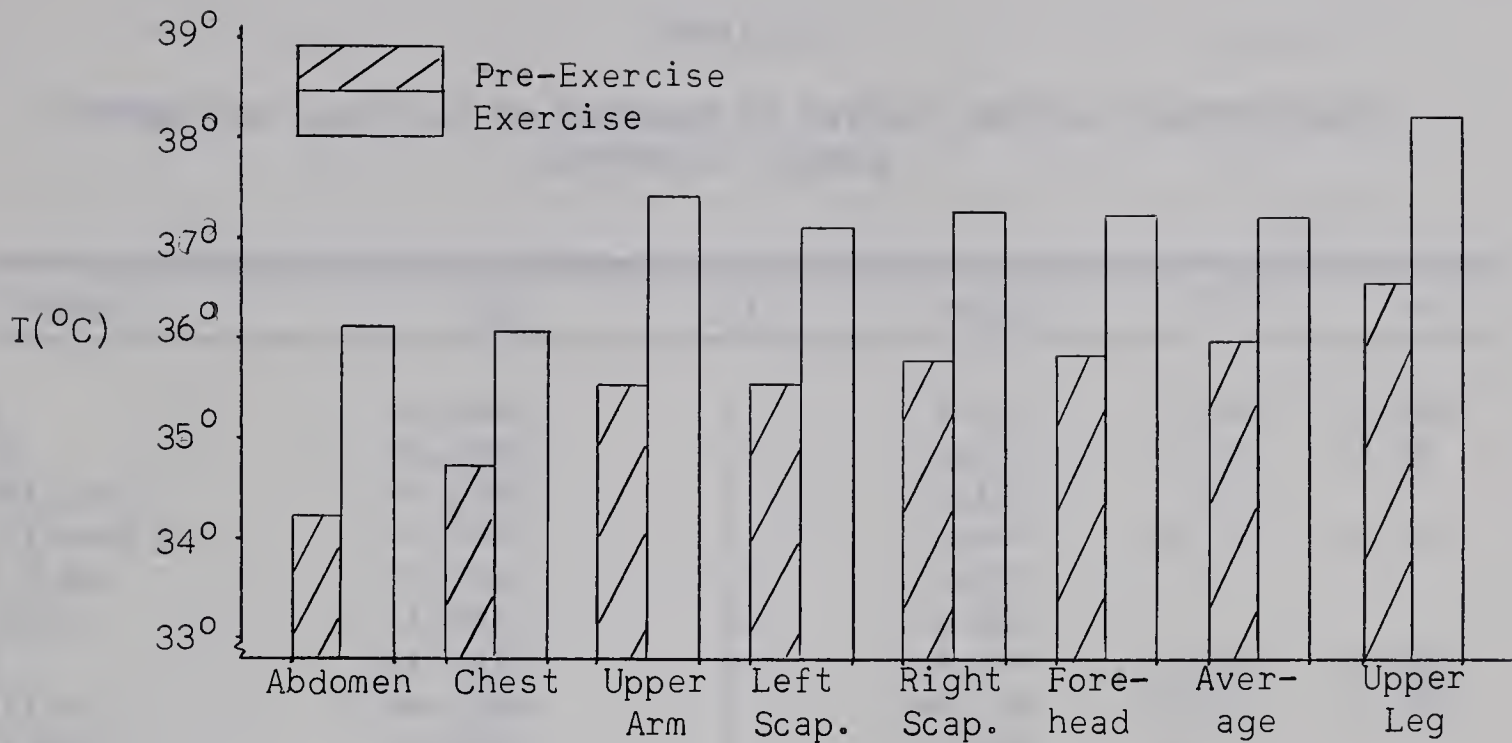
Figure 6: Average Pre-Exercise and Exercise Surface Temperatures

is the overall average (n = 288) of these temperatures excluding that of
the upper leg. It must be emphasized that exercise surface temperatures
were averaged over all conditions and thus each has the effects of the
independent variables confounded within it. The raw data is given in
Tables G and H, Appendix III.

The surface temperatures of all non-exercising parts studied
increased with exercise. Average increase was $1.48^{\circ}C$ with the range
from 1.22° - $1.88^{\circ}C$. The order of increase from smallest to largest
was right scapula, left scapula, upper arm, forehead, abdomen and chest.
Upper leg surface temperature increased an average of $1.35^{\circ}C$ (the same
as left scapula) over the twenty-four conditions.

A closer examination of surface temperature changes with exercise
is given by Tables IX and X and Figures 7 and 8. The raw data is given
in Table I, Appendix III.

TABLE IX

SUMMARY OF ANALYSIS OF VARIANCE OF AVERAGE SURFACE TEMPERATURE
DIFFERENCE SCORES

Source	SS	d.f.	M.S.	F	P
H	2.1252	1	2.125	6.92	<.025
WL	0.8254	2	0.413	1.34	>.25
WL(lin.)	0.1250	1	0.125	--	
WL(quad.)	0.6667	1	0.667	2.17	>.10
H X WL	0.3154	2	0.158	--	
Error	1.8413	6	0.307		
T	44.3831	3	14.794	50.98	<.005
T(lin.)	44.1184	1	44.118	152.02	<.005
T(quad.)	0.0352	1	0.035	--	
T X H	4.3515	3	1.451	5.00	<.025
T(lin.) X H	3.3370	1	3.337	11.50	<.005
T(quad.) X H	0.2269	1	0.227	--	
T X WL	0.3488	6	0.058	--	
T X H X WL	2.1304	6	0.355	1.22	>.25
Error	5.2237	18	0.290		

Since difference scores were employed in the analysis of variance,
the same assumption discussed under "Oesophageal Temperature Changes
with Exercise" holds. However, in this case, the slope of the common
within-groups regression line was 1.039 and hence the increase in error
variance was slight.

TABLE X

SUMMARY OF DUNCAN'S NEW MULTIPLE RANGE TEST OF AVERAGE SURFACE
TEMPERATURE CHANGES ($^\circ$C) WITH AMBIENT TEMPERATURE

Levels	25°	29°	33°	37°
Means	0.28	1.01	1.98	2.82

Differences (P = .05)

The range test showed average surface temperature increments to differ for each ambient temperature studied. These increments were arranged (see Figure 7) such that the linear component of the trend accounted for slightly over 99.5 per cent of the variance due to T.
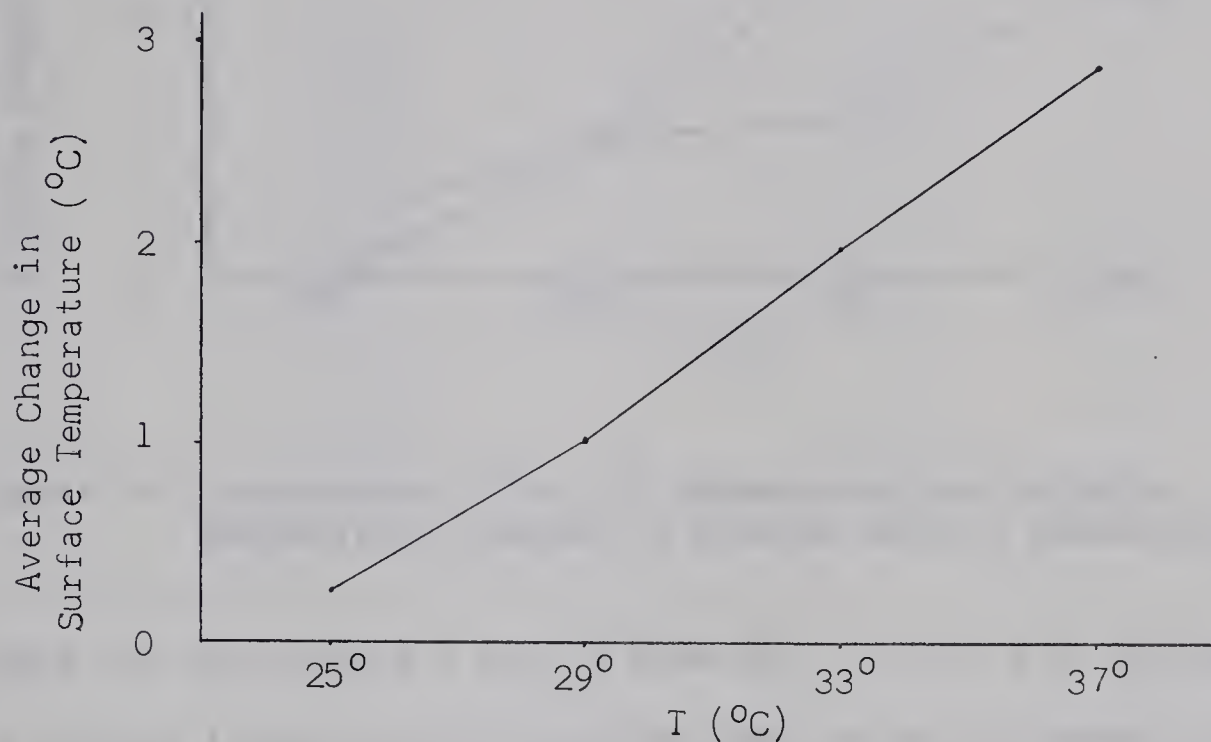
Figure 7: Average Surface Temperature Changes with Ambient Temperature.

The significant interaction effect of ambient temperature and relative humidity was due primarily (95.7 per cent) to the difference in linear trends of the two relative humidity conditions over the four temperatures studied. Figure 8 confirms this finding.

Work load did not affect exercise surface temperature averaged from non-working parts of the body. Neither did it affect exercise surface temperature taken over an exercising body part (upper leg). As shown in Table XI (raw data given in Table J, Appendix III), only T and T X H significantly affected this dependent variable.
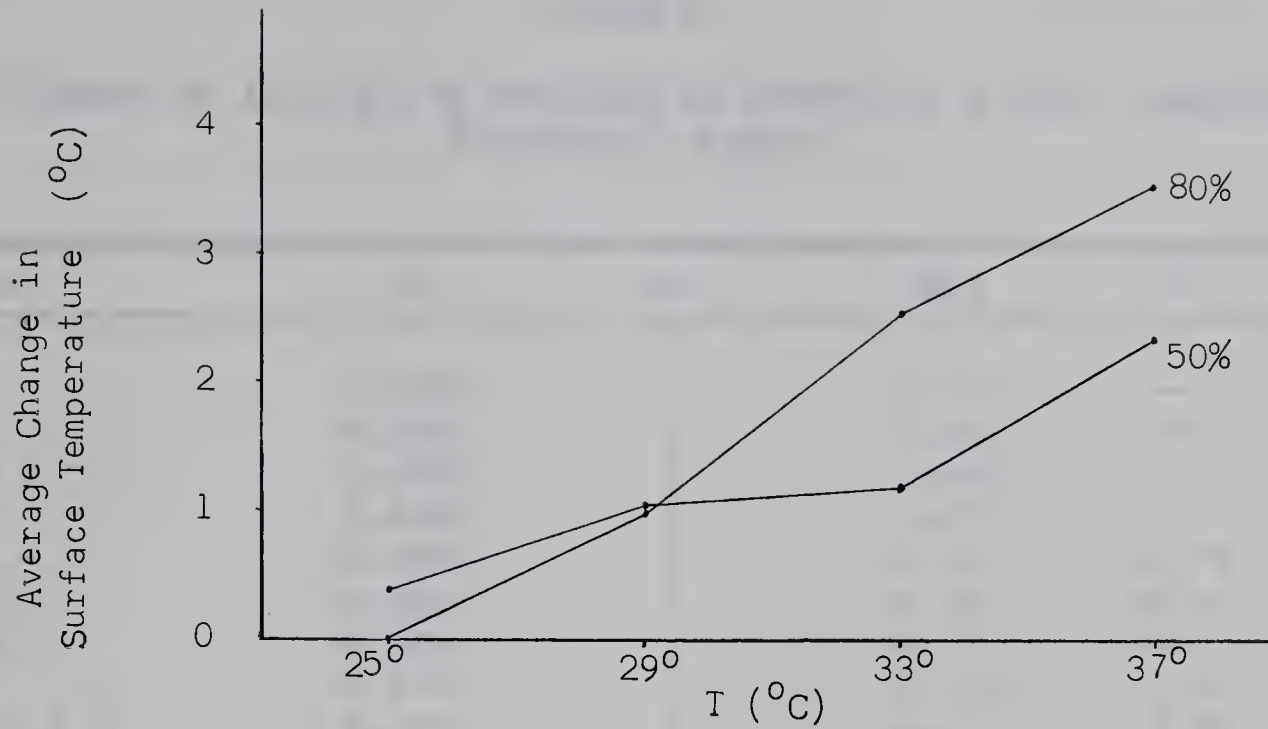
Figure 8: Interaction Effect of Temperature and Relative Humidity on Changes in Average Surface Temperature.

Table XII and Figures 9 and 10 show that T and T X H affected upper leg surface temperature in much the same manner as average surface temperature.
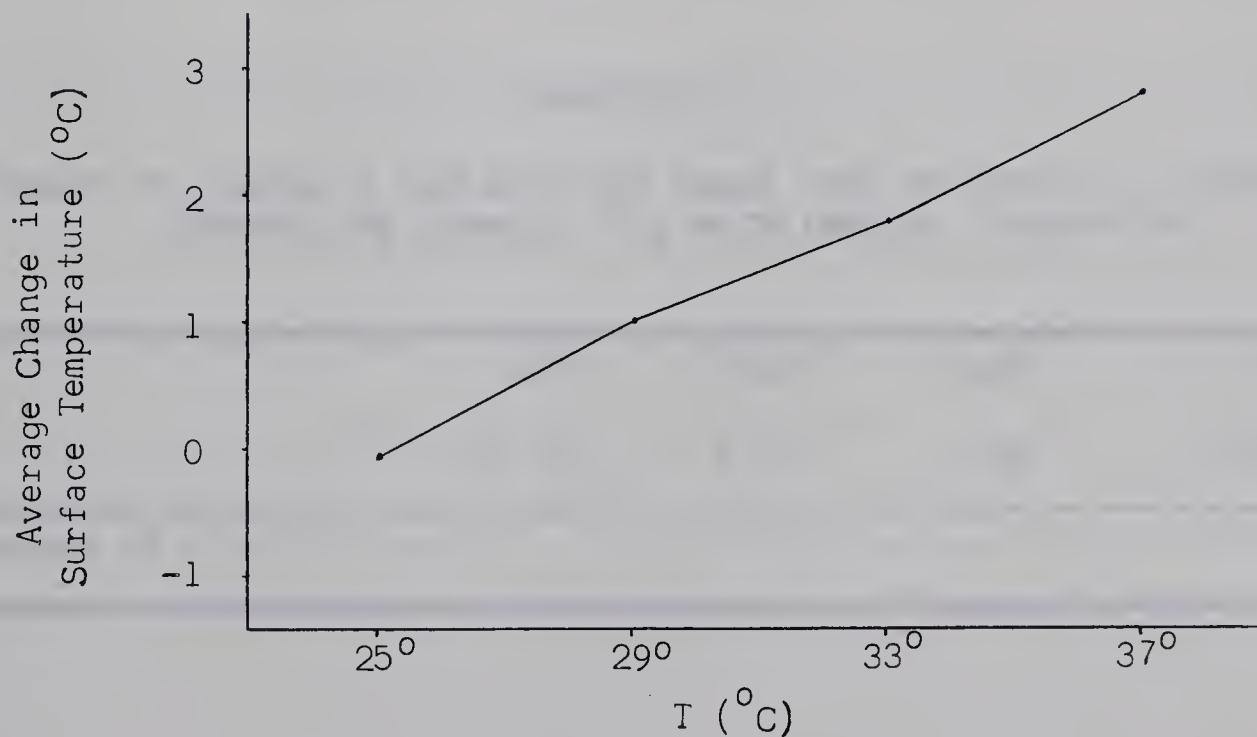
Figure 9: Upper Leg Surface Temperature Changes with Ambient Temperature.

TABLE XI

SUMMARY OF ANALYSIS OF VARIANCE OF UPPER LEG SURFACE TEMPERATURE
DIFFERENCE SCORES

Source	SS	d.f.	M.S.	F	P
H	0.4602	1	0.460	—	
WL	0.0904	2	0.045	—	
H X WL	1.0930	2	0.546	—	
Error	8.0288	6	1.338		
T	51.9940	3	17.331	24.79	.005
T(lin.)	51.8010	1	51.801	74.08	.005
T(quad.)	0.0169	1	0.017	—	
T X H	6.8773	3	2.292	3.28	.05
T(lin.) X H	6.1710	1	6.171	8.83	.01
T(quad.) X H	1.4984	1	1.498	2.14	.10
T X WL	6.3379	6	1.056	1.51	.10
T X H X WL	1.6821	6	0.280	—	.10
Error	12.5862	18	0.699		

TABLE XII

SUMMARY OF DUNCAN'S NEW MULTIPLE RANGE TEST OF UPPER LEG SURFACE
TEMPERATURE CHANGES ($^{\circ}$C) WITH AMBIENT TEMPERATURE

Levels	25°	29°	33°	37°
Means	-0.04	1.03	1.80	2.80

Differences (P = .05)

At 25°C ambient temperature, upper leg surface temperatures decreased very slightly with exercise (Figure 9).

The T X H interaction occurred primarily at low ambient temperature (see Figure 10).
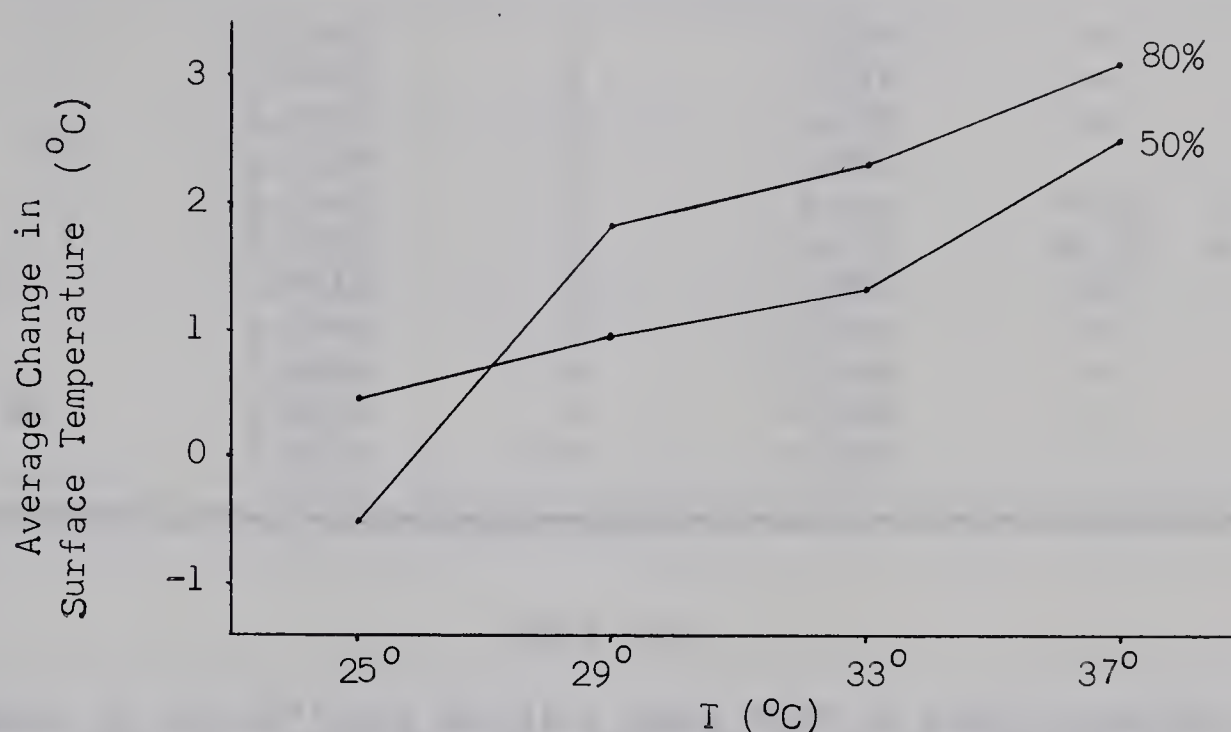
Figure 10: Interaction Effect of Temperature and Relative Humidity on Changes in Upper Leg Surface Temperature.

Comparison of Surface Temperatures Over Exercising and Non-Exercising

Parts

The analysis of variance of difference scores summarized in Table XIII (raw data given in Table G, Appendix III) shows that the differences between average and upper leg exercise surface temperatures were affected only by T.

TABLE XIII

SUMMARY OF ANALYSIS OF VARIANCE OF EXERCISING/NON-EXERCISING SURFACE
TEMPERATURE DIFFERENCE SCORES

Source	SS	d.f.	M.S.	F	P
H	0.0352	1	0.035	--	
WL	0.4363	2	0.218	--	
H X WL	1.8754	2	0.938	--	
Error	6.3238	6	1.054		
T	6.1840	3	2.061	6.55	< .005
T(lin.)	5.0750	1	5.075	16.14	< .005
T(quad.)	0.0019	1	0.002	--	
T X H	0.7940	3	0.265	--	
T X WL	1.3504	6	0.225	--	
T X H X WL	1.6079	6	0.268	--	
Error	5.6613	18	0.315		

TABLE XIV

SUMMARY OF DUNCAN'S NEW MULTIPLE RANGE TEST OF EXERCISING/NON-
EXERCISING SURFACE TEMPERATURE CHANGES WITH AMBIENT TEM-
PERATURE

Levels	37°	33°	29°	25°
Means	0.58	1.04	1.16	1.59

Differences (P = .05)

Table XIV shows a significant difference in effect between all
pairs of ambient temperatures examined.

Figure 11 demonstrates the linearity of temperature effect on
these difference scores which tended to decrease with increasing ambient
temperature. Thus, as ambient temperature increased, upper leg surface
temperatures approached that of the rest of the body.
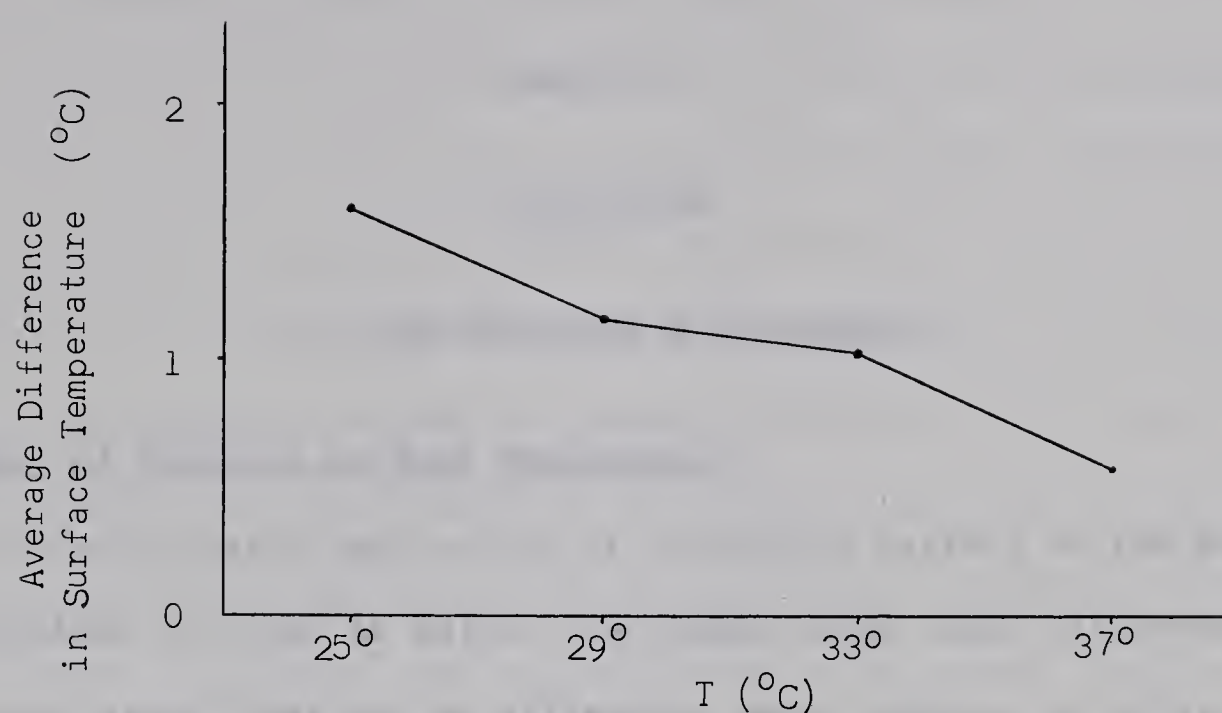
Figure 11: Average Upper Leg Surface Temperature Changes with
Ambient Temperature.

As pointed out in Chapter III, "Limitations of the Statistical
Analysis," results in this section are open to question because of the
inability to assess the probabilities associated with the various F-
ratios. Probabilities have been stated as if a non-conditional design
had been employed, that is, they have been read from the usual F tables.

CHAPTER V

DISCUSSION

I.   PRE-TREATMENT MEASUREMENTS

The Effect of Practice on Work Performance

The anticipated application of correction factors to the depen-
dent variables in order to adjust for unequal work loads was rendered
unnecessary since there was no difference among subjects or trials in
bicycle ergometer performance, measured by the number of revolutions
made during the six-minute exercise period. Low variability was attri-
buted to the high cycling skill of the subjects.

The Effect of Thermistor Ingestion on Non-Exercise Heart Rate

Ingestion of the thermistor increased non-exercising heart rates
an average of approximately 20 beats/min. on each trial. This was not
a simple additive effect however, since the coefficient of correlation
between pre- and post-thermistor heart rates was only 0.69. It is
entirely possible that the thermistor-swallowing competition introduced
to mitigate the discomfort of ingestion contributed to the increased
post-thermistor heart rate since the coefficient of correlation between
this measure and speed of ingestion was 0.73. However, it should be
noted that the heart rate was just as large on the first day at which
time the competition had not yet been introduced. These data do not
support the suggested (44) reflex bradycardia upon introduction of a
thermistor into the oesophagus.

Changes in Pre-Exercise Heart Rate Over Successive Trials

The significant linear trend of the non-significant decrease in pre-exercise heart rates over the four trials suggests that this decrement may have achieved significance had further trials been studied. It suggests also that subjects became less anxious about the post-thermistor ingestion experimental situation with successive exposure. In this regard it is interesting to note that the difference between pre-exercise and pre-thermistor heart rates tended to increase with trials; that is, subjects did not grow less anxious about thermistor ingestion.

II.   RELATION OF RESULTS TO THE HYPOTHESES AND THE LITERATURE

Exercise Heart Rate

Exercise heart rate varied directly with work load as hypothesized. The significant linear trend of mean heart rates over the three work loads adds further qualified support to the widely accepted postulate of a linear function relating heart rate and work load. This support must be tempered by the limtations advanced under "Exercise Heart Rate," Chapter IV.

Exercise heart rate also varied directly with ambient temperature as hypothesized. The variation cannot, however, be explained by a simple linear function as Brouha (11) suggests since temperature did not affect heart rates at 25° or $29^{o}C$ but did have an effect, approximately three and eight beats respectively, at 33° and $37^{o}C$. This is in close agreement with the findings of Lind (38) who found heart rate unrelated to temperature below but showing parabolic increase with

temperature above, 25°-26°CET. The results could also explain why

Brouha et al. (13) found no difference in the heart rate response to

five minutes light exercise under three different thermal conditions,

since the conditions ranged from 25°C and 43 per cent relative humidity

to 32.2°C and 82 per cent relative humidity. Alternatively, it is

possible that the results of Brouha et al. were due to the low work loads

involved (even though no evidence of a temperature X work load inter-

action accrued from the present study) since Suggs and Splinter (51)

found a significant temperature by work load interaction effect on the

heart rate of their subject. This interaction they were unable to

explain. No evidence in support of Dill's suggestion (19) that high

temperatures may aid brief intense exercise resulted from the present

study either, unless increased heart rate be construed as an aid to

exercise.

The postulated direct variation of heart rate with relative

humidity failed to appear. In fact, the humidity effect, though non-

significant, was inverse with the low and high humidity conditions

elliciting average heart rates of 141.4 and 144.5 beats/min. respec-

tively. This is in agreement with the findings of Hall (29) and Suggs

and Splinter (51) and the suggestion by Dill (19).

In addition, no evidence in support of the postulated (and

demonstrated (51) temperature by humidity interaction effect on heart

rate resulted. At the two highest temperatures, heart rates were nearly

identical at the different relative humidity levels.

Oesophageal Temperature Changes with Exercise

The hypothesis of a direct variation between work load and oesophageal temperature was upheld. Although the linear trend was significant and the quadratic trend was not, it is apparent from Figure 3, Chapter IV, that the relationship between them is not a simple linear one. No suggestion as to the form of the relationship is offered by the many studies (38,42,46,47,58,61,62) which offer evidence that increased work loads are associated with increased deep body temperature.

The results of the analysis of variance did not support the postulated oesophageal temperature-ambient temperature dependency. However, the range test results, which showed internal temperature significantly lower at $25^{o}C$ than at any other temperature, provide con-cilliatory evidence in the disagreement between Nielsens (42,43) and other researchers (37,38,47,51,62). The former claim that internal temperature is independent of ambient temperature but their experiments have not investigated temperatures beyond $30^{o}C$. The latter claim that this independence only exists below some critical temperature, estimates of which range from $26^{o}CET$ (38) to $31^{o}C$ saturated (61). The critical temperature estimate from the present study falls in the middle of this range. Agreement with the "critical temperature studies" ends here, however, since they unanimously demonstrate (38,61,62) a positive expo-nential relationship between ambient and internal temperature beyond the critical point while the present study suggests a negative exponential relationship (see Figure 2, Chapter IV).

This problem is further compounded by the possibility of a temperature X work load interaction effect on internal temperature which

is suggested by the results (but not discussed by the authors) of the

aforementioned studies. For example, Lind (38), found the rectal

temperature response to one hour of treadmill exercise to commence

variation with ambient temperature at 27°, 28° and 30°CET for work loads

of 420, 300, and 180 k cal./hr. respectively. Similarly, Wyndham et al.

(61) give the critical temperatures as approximately 30° and 32°C

(saturated) for four hour energy expenditures of 150 and 100 $Cal/m^2/hr$

respectively. In an extension of this study (62) they give the threshold

temperatures, above which internal temperatures were affected, as 29°,

30° and 32°C (saturated) respectively for work loads of 240, 150, and

100 $Cal/m^2/hr$. These results imply a temperature X work load inter-

action and increase the difficulty of comparing studies of internal

temperature response to ambient temperature where different work loads

are involved. The results of the present study tend to support the above

observations although the temperature X work load interaction did not

achieve significance. Figure 5, Chapter IV, shows the difference between

the work load conditions to be quite different at the different tempera-

tures. This difference is in the direction suggested by the above

studies within the temperature ranges examined by them.

In support of Nielsen's findings (42), the hypothesized humidity

effect on internal temperature failed to achieve significance although

it was in the direction anticipated; the high humidity condition resulted

in a 50 per cent greater increase in oesophageal temperature than the

low one (0.35° versus 0.50°C).

Similarly, no significant temperature X humidity interaction

occurred. The small effect present was contrary to expectations since

80 per cent relative humidity proved less stressful than 50 per cent relative humidity at the lowest temperature (see Figure 4, Chapter IV).

Average Surface Temperature Changes with Exercise

As hypothesized, relative humidity had a statistically signifi-cant effect on average surface temperature; high relative humidity resulted in a 30 per cent larger increase in surface temperature with exercise than did low relative humidity.

In complete contradiction to the findings of Winslow and Gagge (58), surface temperatures tended to be higher during work than rest. The three exceptions occurred (Table F, Appendix III) not at the high temperatures, as suggested, but at the lowest temperature.

The results of the present study, though non-significant, dis-agree with those of Robinson et al. (47), who found surface temperatures to decrease slightly with increasing work load, and agree with those of Winslow and Gagge (58) who found average surface temperature increased with work load until the latter became heavy, at which point it de-creased. In the present study the average increase in average skin temperature was 1.4°, 1.6°, and $1.5^{\circ}C$ for the 450, 750, and 1,050 kpm/min. work loads respectively.

Average surface temperature, in agreement with Bernauer (8) and Robinson et al. (47) but in disagreement with Winslow and Gagge (58), showed significant variation with ambient temperature as postulated.

Also as postulated (hypothesis #5), average surface temperature was higher at 80 per cent than at 50 per cent relative humidity, for the highest temperature conditions. The difference was considerable--approxi-mately $1.2^{\circ}C$ (mean of 48) at both 33° and $37^{\circ}C$. Surface temperature was

thus the only parameter affected by a temperature X humidity interaction.

Surface Temperature Changes over an Exercising Muscle

Averaged over the twenty-four conditions, upper leg surface temperature increased an average of 1.35°C with exercise. This was the second smallest increase of any body part and was affected only by ambient temperature and its interaction with relative humidity. The temperature effect was positive and linear; upper leg surface temperature was higher at higher ambient temperatures. The slight decrease in surface temperature at 25°C is interesting since no suggestion of such an occurrence is made in the literature (18,26,27,36). A possible explanation lies in the different methods of exercise employed. The above studies all employed isometric exercises whereas in the present study, measurement was made over an isotonically contracting muscle. Since any movement is known to increase convective heat loss (58), it is suggested that the increased convective cooling was sufficient, at 25°C, to offset intramuscular thermogenesis due to pedalling.

The temperature X humidity interaction effect on upper leg surface temperature was such that high humidity caused an increase in surface temperature at high ambient temperatures and a decrease at low ambient temperatures (see Figure 10, Chapter IV).

Surface Temperature Differences Between Exercising and Non-Exercising Parts

The differences between average and upper leg surface temperatures during exercise, though difficult to evaluate because of the reasons advanced in Cahpter IV, were the reverse of Hypothesis #4 (surface

temperature is highest over exercising muscles). Thus, in forty-six

out of fifty-eight cases (see Table J, Appendix III) average surface

temperature was greater than upper leg surface temperature after six

minutes of cycling. The reason for the discrepancy between the hypothe-

tical and empirical results is attributed to the unrealistically high

(15,60) "average surface temperature" measurements. In order to simpli-

fy experimental procedure, surface temperature was averaged only from

the head and trunk (even the upper arm location involved was proximal

to the trunk). Cooler limb measurements were thus omitted, yielding an

average which may have been misleading.

An examination of Figures 7, 9, and 11, Chapter IV, demonstrates

the interpretive difficulties inherent in the use of difference scores.

The graph of Figure 11 is not a simple subtractive function of the

graphs in Figures 7 and 9, as might be expected, since the latter are

pre-exercise level dependent and the former only exercise level depen-

dent.

III. PHYSIOLOGICAL INTERPRETATION OF RESULTS

The discussion of the results to this point has consisted merely

of evaluating the hypotheses of this study in terms of related findings

in the literature. It remains to give an explanation of the results in

physiological terms. Such an explanation is facilitated by a considera-

tion of each independent variable in turn and the effect it had on the

dependent variables. (This is in contrast to the plan of Section II

where each dependent variable was examined in relation to changes in the

independent variables.) Discussion is focused by Figures 1 to 3 in which

results have been rearranged and synthesized in the manner outlined.

Relative Humidity Effects

Figure 1 demonstrates the effect of humidity variation on the parameters investigated. (OT refers to changes in oesophageal temperature, $\overline{ST}$ refers to changes in average surface temperature and HR stands for heart rate.)

With an increase of relative humidity from 50 to 80 per cent, surface temperature increased $0.4^{\circ}C$ (statistically significant). This increase may be attributed to the decreased effectiveness of evaporative cooling resulting from a reduction of the air-to-skin vapor pressure differential (59). That is, the increase in surface temperature cannot, in this case, be attributed to increased skin blood flow alone. That vasodilatation did not occur (or was very limited) is substantiated by the lack of heart rate increase with increased humidity.

Since surface temperature was elevated, it may be concluded that radiative heat loss increased but, in the "absence" of evaporative cooling, internal body temperature rose slightly.

The failure of heart rate to increase with humidity as hypothesized is possibly due to the brevity of the exercise period. Perhaps if exercise had been prolonged the continued increase in internal temperature (42) would have led to vasodilatation and tachycardia (56).

Work Load Effects

The effect of work load on the three variables was as postulated, with heart rate and internal temperature increasing with work load (see Figure 2). Heart rate responded to work load increments between groups
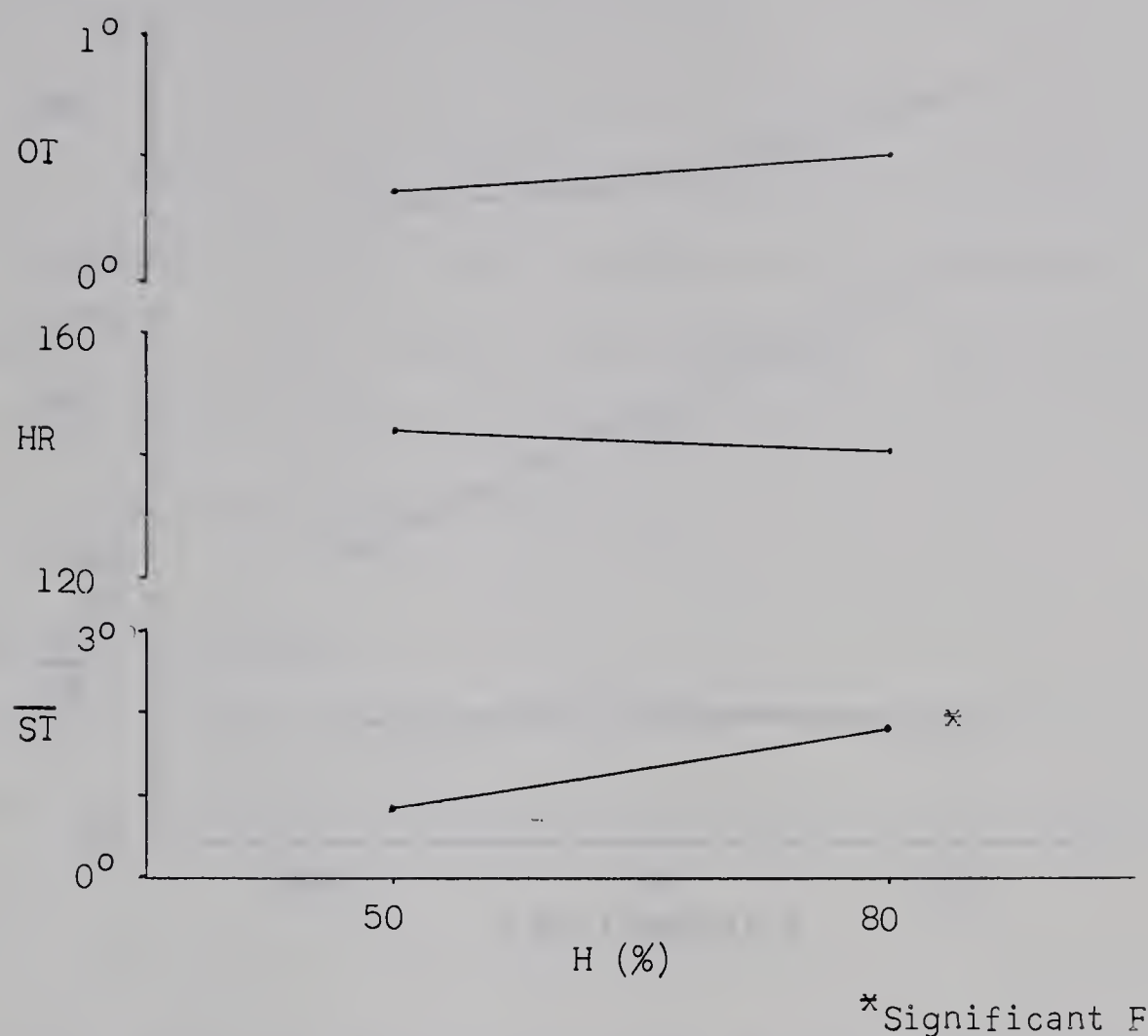
Figure 1: Effect of Relative Humidity on Heart Rate and Body
Temperature.

in the same manner which is well established (6,51) for work load incre-

ments within groups. Assuming heart rate to be an index of exercise

stress (5,6,10), the physically equi-spaced work intervals seem to be

physiologically equi-spaced as well. The same does not hold, however,

if internal temperature is assumed an index of exercise stress (10).

The difference in oesophageal temperature between the inter-

mediate and high work load was roughly three times as great as the

difference between the low and intermediate work loads. In view of the

heart rate response, it is unlikely that the increase in exercise stress

was in fact threefold. It is more likely that the difference in

oesophageal temperature responses was due to the nature of the experimental
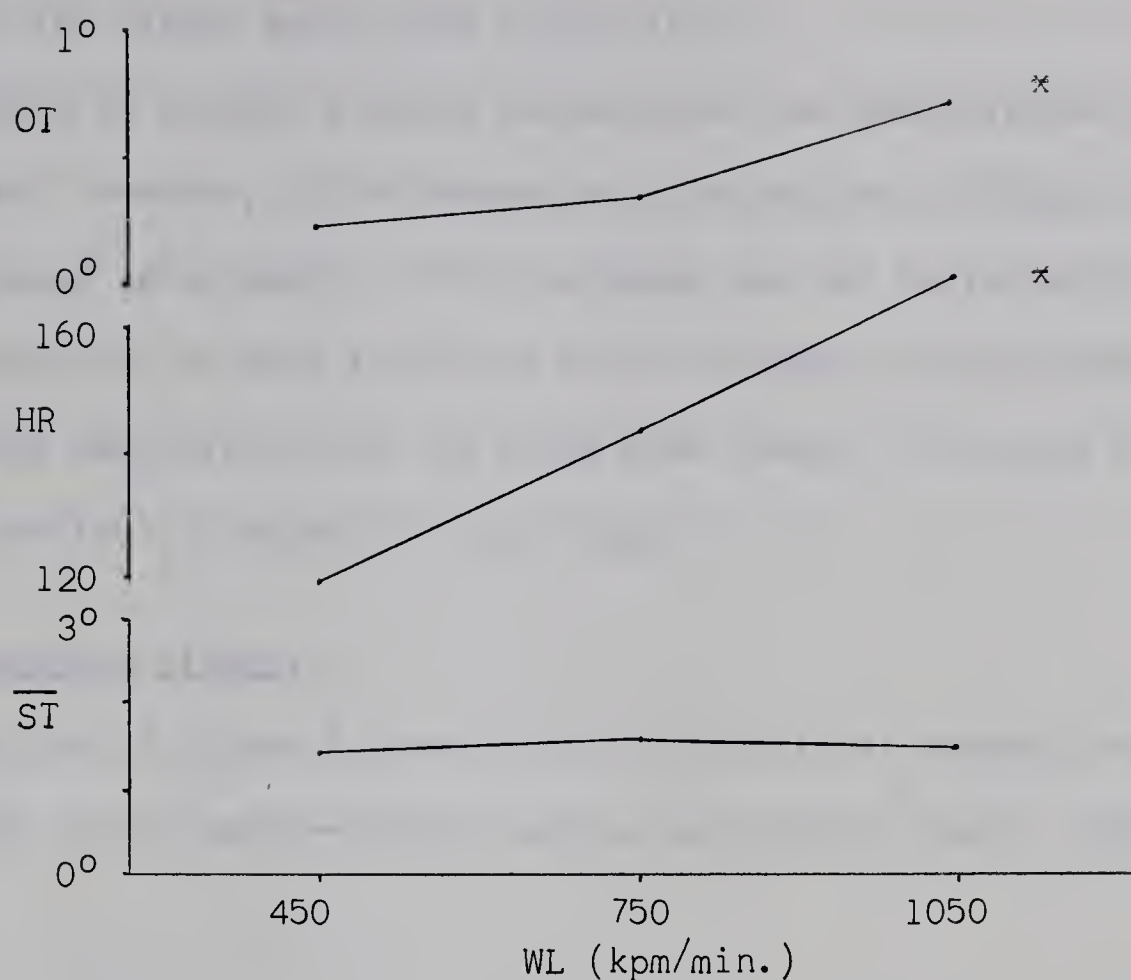
Figure 2: Effect of Work Load on Heart Rate and Body Temperature.

design which resulted in differences in physical characteristics among

the subjects at each work load.

On a bicycle ergometer heat output is proportional to work load

(45) whereas heat loss is dependent,in part,on the effective radiation

area (58) of the body. That is, at any given work load, a large subject

produces the same amount of heat as a small one but has less difficulty

excreting it. If the ratio of height to weight be considered an (albeit

crude) index of surface area, then it can be argued that the deviation

from linearity of the internal temperature variation with work load

might have been due to the smaller average surface area of the subjects

who performed at 450 kpm/min: 2.16 cm/kg compared with 2.36 and 2.28

cm/kg for the two larger work loads respectively.

No change in average surface temperature over the different work loads resulted. However, since oesophageal temperature increased, heat storage increased considerably. This increase was not reflected by surface temperature, so heat loss must have increased. Since thermal conditions were equivalent over the three work loads, it follows that evaporative cooling increased with work load.

Ambient Temperature Effects

Inspection of Figure 3 shows that the effects of temperature are best discussed in two parts--effects below, and effects above, $29^{\circ}C$.
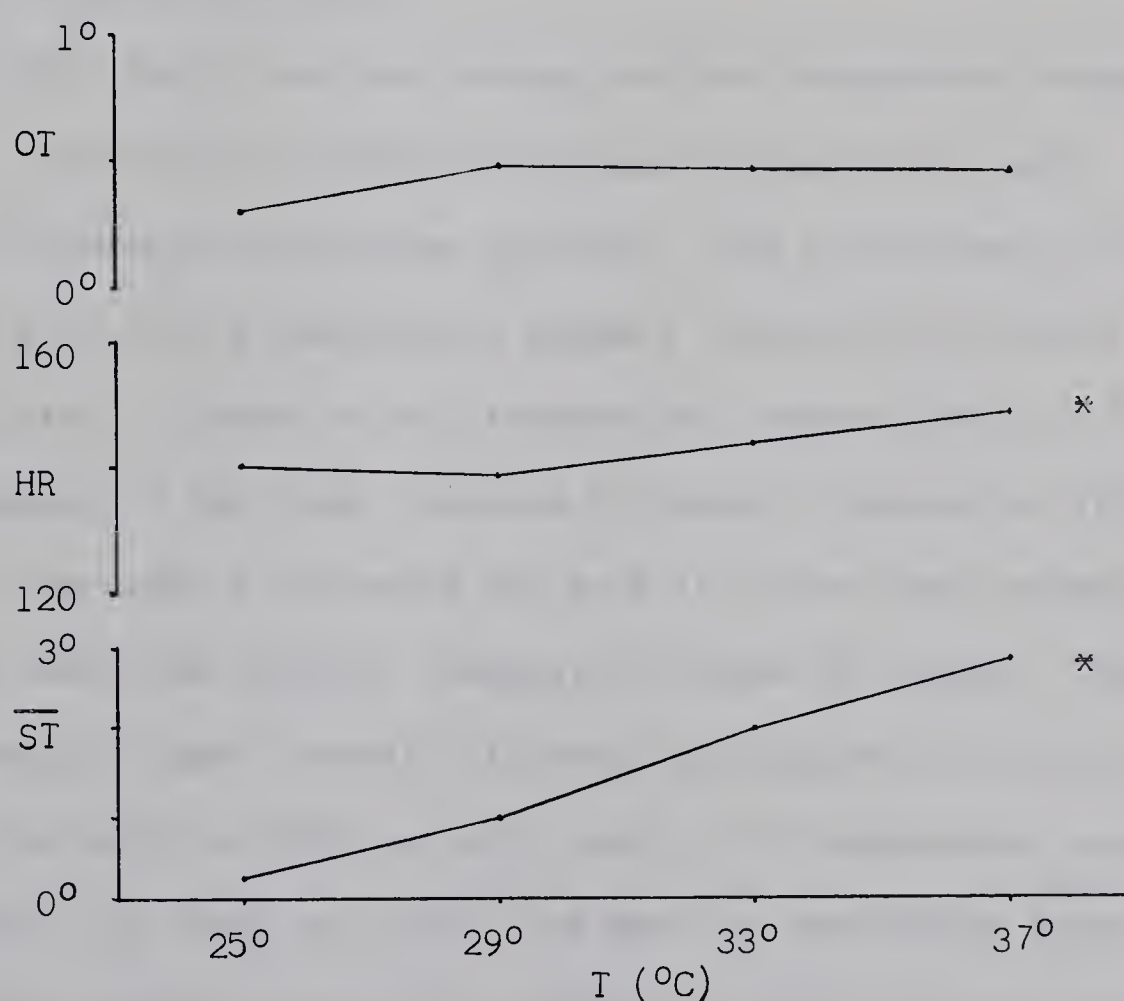
Figure 3: Effect of Ambient Temperature on Heart Rate and Body Temperature.

As temperature increased from 25° to $29^{\circ}C$, both surface and internal temperatures increased whereas heart rate did not. Since heart rate did not show corresponding increase with skin temperature, and since humidity conditions were equivalent, it must be assumed that vasodilatation did not occur. Rather, the increased body temperature readings suggest that heat storage occurred in this range. This is precisely what would be expected in "basal" conditions (see Introduction, Chapter II). That is, if allowed to recline at $25^{\circ}C$, which is well within the zone of metabolic heating (32), subjects would eventually attempt to store heat by shivering (30). It is suggested that the light work load involved (average of 4,500 kpm) acted as a substitute for autonomic metabolic heating.

Above $29^{\circ}C$, heart rate and average surface temperature showed statistically significant increments with each temperature level, while internal temperature remained constant. The simultaneous increase of heart rate and surface temperature suggest increased skin blood flow. However, the total increase in skin temperature (approximately $1.7^{\circ}C$) was small compared to the total increase in ambient temperature ($8^{\circ}C$). That is, skin temperature increased but much less than room temperature. At the same time internal temperature showed no change. These two facts strongly suggest steadily increasing evaporative cooling above $29^{\circ}C$. Certainly at $37^{\circ}C$, at which point air temperature exceeded skin temperature, all heat loss must have been by evaporative means.

The above treatment shows the interpretive difficulties which result when no estimate of the extent of evaporative cooling is available. The precise role which evaporation has played in any given skin

temperature is unknown. This seriously limits the utility of surface temperature as an index of skin blood flow. Where surface temperatures and heart rate increased concomitantly, one may assume vasodilatation occurred, but where surface temperature increased with constant heart rate one can only conclude that evaporative heat loss decreased and vasodilatation did not occur. Where heart rate increased with constant surface temperature it is impossible to determine what changes occurred in skin blood flow.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was to examine the effects which tempera-
ture, humidity and work load variations have on fitness test performance.

Twelve male adult subjects were tested four times each at
temperatures of 25°, 29°, 33°, and 37^oC. Each subject performed at a
constant humidity (50 per cent or 80 per cent)--work load (450, 750,
or 1,050 kpm/min.) combination. The independent variables were con-
trolled by employing a bicycle ergometer in an environmental chamber.

Fitness test performance was inferred from the heart rate res-
ponse to six minutes of exercise. To aid the physiological interpre-
tation of results, internal temperature was recorded from the oesophagus
and average surface temperature from six points on the skin. As a
sub-problem, the average surface temperature was compared with the
surface temperature over an exercising muscle group (quadriceps femoris).

To test the hypotheses (increase in surface temperature over
exercising muscles, the effect of humidity on surface temperature, the
effects of temperature, humidity and work load on heart rate and internal
temperature, and the interactive effect of temperature and humidity on
the latter two) analyses of variance, Duncan's New Multiple Range Test,
and orthogonal polynomials were applied to the data.

Conclusions

Tempered by the limitations inherent in the sampling procedure, the experimental design and the methods employed, the following conclusions have been drawn from this study.

1. Exercise heart rate is increased in temperatures above about $30^{o}C$. The effect is slight at 33° but considerable at $37^{o}C$.

2. Heart rate is linearly related to work load.

3. Heart rate and oesophageal temperature are not affected by high humidity or by high humidity and high temperature combined.

4. Internal temperature increases with work load but not in simple proportion.

5. Exercise oesophageal temperature is increased in ambient temperatures above $25^{o}C$.

6. Surface temperature over an exercising muscle group is lower than surface temperature averaged from the trunk.

7. Surface temperatures are higher during work than rest.

8. Average surface temperature increases with increasing humidity and is greatest when high temperature and high humidity are in combination.

9. Surface temperature is linearly related to ambient temperature.

10. For tests of short duration, physical fitness testing conditions can be standardized by setting thermal limits of 25° to $29^{o}C$ and 50 per cent to 80 per cent relative humidity.

Recommendations

From knowledge gained during this study, the following recommendations to researchers contemplating similar experimentation are offered:

1. absolute body temperatures rather than difference scores be analyzed,

2. some index of sweating or evaporation be included, and

3. if average surface temperature is to be examined then measurements be made from points more representative of the total skin surface.

Similarly, it is recommended that the following questions receive experimental consideration:

1. Can the above conclusions be generalized to a younger population?

2. Would similar results occur if the duration of exercise were increased?

3. Would performance be affected by relative humidity values lying outside the range studied?

4. At what point does temperature begin to affect the heart rate response?

5. Would similar results occur if fitness tests were conducted under equal but non-experimentally-induced thermal conditions?

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APPENDICES

APPENDIX I

SELECTED POINTS ON THE CORRECTED EFFECTIVE TEMPERATURE SCALE

(From Bernauer (11) after Bedford (1936))

Dry-Bulb Temperature ($^{\circ}$C)	15°	20°	26°	32°	38°
Relative Humidity (per cent)	49	55	50	58	56
Corrected Effective Temperature ($^{\circ}$C)	10°	16°	21°	27°	32°

APPENDIX II

PHYSICAL CHARACTERISTICS AND SEQUENCE OF TESTING OF SUBJECTS

TABLE A

PHYSICAL CHARACTERISTICS OF SUBJECTS

Subject No.	Height (cm)	Weight (kgm)	Age (yrs)
1	172.7	81.6	25
2	177.8	95.2	23
3	186.8	80.7	31
4	167.6	68.0	27
5	184.2	84.8	30
6	180.3	77.1	27
7	175.3	78.0	25
8	172.1	61.6	31
9	177.8	70.3	27
10	182.9	72.5	25
11	182.2	90.7	31
12	185.4	86.1	27
Mean	178.8	78.9	

TABLE B

TESTING ORDER FOR EACH SUBJECT

| Subject No. | Temperature (^{o}C) | | | |
	Day 1	Day 2	Day 3	Day 4
1	33	29[a]	35	39
2	29	25	33	37
3	29	33	25	37
4	25	33	37	29
5	25	37	29	33
6	25[b]	33[b]	29	37
7	29	33	37	25
8	37[b]	33[b]	29[b]	25[b]
9	37	29	33	25
10	37	33	25	29
11	25	29	33	37
12	37	33	25	29

[a]Oesophageal temperature reading lost; trial repeated two days after Day 4.

[b]Xylocaine administered.

TABLE C

TESTING PERIODS FOR EACH SUBJECT

| Subject No. | Hours After Midnight | | | |
	Day 1	Day 2	Day 3	Day 4
1	18.30	11.00	13.00	14.15
2	15.30	12.00	19.00	14.15
3	14.00	14.00	9.00	10.00
4	15.30	15.00	15.00	12.30
5	18.30	16.00	11.00	9.15
6	8.30	18.00	17.00	9.45
7	17.30	20.00	20.00	9.45
8	12.00	12.00	12.00	12.30
9	14.00	8.30	13.45	8.30
10	20.00	8.30	8.30	8.30
11	20.30	11.15	11.15	14.30
12	20.30	11.00	11.00	10.30

APPENDIX III

RAW DATA

TABLE A

NUMBER OF REVOLUTIONS OF BICYCLE ERGOMETER BY EACH SUBJECT ON
EACH TRIAL

Subject	Revolutions Made in Six Minutes			
No.	Day 1	Day 2	Day 3	Day 4
1	303	302	303	300
2	--[a]	300	303	302
3	303	303	301	302
4	--	303	302	301
5	304	301	--	300
6	304	303	303	300
7	304	304	303	300
8	304	303	302	305
9	302	303	302	304
10	298	302	301	304
11	301	295	303	300
12	305	--	303	300

[a]Data not recorded.

TABLE B

PRE- AND POST-THERMISTOR HEART RATES FOR EACH TRIAL

Subject	Heart Rates (beats/min.)							
No.	Trial 1		Trial 2		Trial 3		Trial 4	
	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
1	75	79	73	84	77	83	69	69
2	91	113	83	118	100	141	83	87
3	87	90	93	124	85	118	90	96
5	83	122	98	113	80	113	85	114
6	69	99	67	95	83	118	75	80
7	70	62	74	69	77	90	62	71
8	62	90	70	100	105	92	67	94
9	85	122	80	91	74	90	73	107
10	83	90	71	90	83	94	78	89
12	78	102	73	87	82	131	92	153

TABLE C

LENGTH OF TIME (SEC.) REQUIRED TO INGEST THERMISTOR AT EACH
OF THE FINAL THREE TRIALS

Subject No.	Trial 2	Trial 3	Trial 4
1	12.0	9.5	9.7
2	101.0	13.0	26.0
3	8.1	10.3	--
4	38.0	10.0	9.5
5	46.0	4.3	4.3
6	122.0	28.0	--
7	68.0	44.0	14.0
8	43.0	41.0	36.0
9	36.0	--[a]	--
10	65.0	65.0	--
11	145.0	12.0	11.2
12	34.0	11.0	4.3

[a]Data not recorded at subject's request.

TABLE D

PRE-EXERCISE HEART RATES (BEATS/MIN.) FOR TWELVE SUBJECTS AT EACH OF
FOUR TRIALS

Subject No.	Day 1	Day 2	Day 3	Day 4
1	66	60	75	66
2	99	90	92	80
3	91	83	87	87
4	63	67	62	52
5	86	97	79	82
6	69	75	79	83
7	68	69	76	63
8	61	67	64	60
9	108	89	84	86
10	83	72	82	79
11	79	73	60	67
12	72	62	72	68

TABLE E

EXERCISE HEART RATE (BEATS/MIN.) RESPONSES TO TREATMENT CONDITIONS

		Subject No.	25°	29°	33°	37°
450	50%	1	99	102	107	108
		2	118	122	122	118
	80%	3	138	119	129	136
		4	110	110	125	129
750	50%	5	130	121	128	141
		6	155	158	149	161
	80%	7	125	132	141	147
		8	149	138	167	161
1050	50%	9	173	176	180	184
		10	180	180	173	182
	80%	11	155	150	148	155
		12	153	159	160	164

TABLE F

PRE-EXERCISE AND EXERCISE OESOPHAGEAL TEMPERATURES (°C) WITH DIFFERENCE SCORES

	Subject No.	25°			29°			33°			37°		
		Pre-X	Ex.	D	Pre-X	Ex.	D.	Pre-X	Ex.	D.	Pre-X	Ex.	D
450 kpm													
50%	1	37.1	37.3	0.2	37.0	37.0	0.0	37.0	37.5	0.5	36.9	37.4	0.5
	2	37.6	37.7	0.1	37.4	37.7	0.3	37.2	37.7	0.5	37.1	37.2	0.1
80%	3	36.8	36.7	-0.1	37.7	37.9	0.2	36.8	37.1	0.3	37.3	37.4	0.1
	4	37.7	37.9	0.2	36.8	37.1	0.3	37.7	37.9	0.2	36.6	36.8	0.2
750 kpm													
50%	5	37.3	37.4	0.1	37.4	37.4	0.0	37.2	37.2	0.0	37.0	37.7	0.7
	6	37.2	37.4	0.2	37.2	37.6	0.4	36.6	36.4	-0.2	--	--	0.2a
80%	7	36.9	37.4	0.5	37.5	38.0	0.5	37.6	37.9	0.3	35.8	36.8	1.0
	8	37.2	37.2	0.0	36.8	37.4	0.6	36.5	37.2	0.7	37.2	37.8	0.6
1050 kpm													
50%	9	36.8	37.2	0.4	37.2	37.7	0.5	37.0	37.5	0.5	37.6	38.3	0.7
	10	36.7	36.9	0.2	36.4	37.4	1.0	36.8	37.5	0.7	37.5	38.2	0.7
80%	11	37.4	38.5	1.1	36.3	37.7	1.4	36.2	37.4	1.2	36.8	37.5	0.7
	12	36.5	37.3	0.8	36.8	37.2	0.4	37.3	38.1	0.8	37.3	37.3	0.0

aDatum estimated.

TABLE G

PRE-EXERCISE SURFACE TEMPERATURES (^{o}C)

	S's	Abdomen	R. Scapula	Forehead	Chest	Deltoid	L.Scapula	Average	Up.Leg
Trial 1	1	34.8	39.2	39.6	39.2	39.8	38.8	38.8	38.4
	2	30.9	35.9	35.0	34.4	33.8	34.6	34.4	33.3
	3	34.7	36.9	36.7	36.1	35.9	36.9	36.4	34.6
	4	34.8	36.0	26.0	37.6	35.4	35.5	37.7	34.8
	5	33.0	34.8	35.4	32.7	35.3	35.2	34.7	33.4
	6	33.7	33.4	33.8	33.4	33.0	32.9	33.3	32.0
	7	36.4	39.0	37.8	37.4	37.5	37.4	37.4	38.0
	8	33.0	35.5	36.3	35.2	34.5	34.9	35.0	35.2
	9	36.3	36.3	37.1	37.9	36.7	37.1	36.9	35.7
	10	31.0	33.8	33.9	33.8	33.2	33.9	33.5	32.8
	11	36.4	34.4	34.4	34.5	34.2	35.2	34.8	32.6
	12	40.4	41.6	42.9	42.3	42.1	42.5	42.0	41.2
Trial 2	1	32.5	36.0	36.9	34.5	35.3	36.1	35.5	34.0
	2	29.6	32.1	34.4	32.2	31.5	32.0	32.5	31.2
	3	35.4	36.5	36.4	35.0	35.2	36.5	36.0	34.5
	4	33.0	36.5	36.8	35.4	34.0	35.6	35.2	34.7
	5	35.5	37.0	37.1	35.7	37.0	36.6	36.6	35.4
	6	33.0	34.5	34.8	33.9	33.5	34.3	34.1	32.6
	7	35.0	37.7	35.3	36.9	37.3	37.2	36.7	36.5
	8	34.7	36.5	37.0	35.5	35.6	35.4	35.8	35.7
	9	36.3	38.2	38.6	37.4	37.5	37.4	37.7	36.2
	10	35.9	37.8	38.3	37.0	37.3	37.5	37.4	35.3
	11	35.4	35.2	35.7	35.1	34.5	34.8	35.2	33.3
	12	34.7	36.8	36.7	35.6	35.8	36.9	36.3	35.1
Trial 3	1	32.7	35.7	37.0	35.2	35.1	35.7	35.7	35.7
	2	29.9	34.4	36.9	32.6	34.0	34.4	34.0	32.3
	3	30.6	34.9	35.9	34.8	35.4	35.2	34.8	33.5
	4	33.2	36.2	37.3	34.3	35.3	36.0	35.6	34.5
	5	34.2	34.9	36.9	35.1	35.7	35.7	35.5	34.8
	6	36.6	36.1	37.4	36.5	36.3	36.4	36.5	35.2
	7	34.6	37.0	38.7	36.3	36.5	37.6	36.9	36.0
	8	36.5	37.5	38.7	37.8	37.3	37.7	37.6	37.5
	9	37.7	38.0	38.7	37.9	37.6	37.7	38.0	37.4
	10	33.9	34.1	35.2	34.1	34.3	34.2	34.4	32.6
	11	34.6	32.7	34.0	32.2	33.0	33.1	33.2	31.2
	12	31.2	34.8	35.6	34.2	34.3	33.9	34.2	33.2
Trial 4	1	31.1	34.5	35.0	34.0	33.4	34.3	33.8	33.9
	2	34.1	36.3	37.8	35.5	36.5	36.5	36.0	35.4
	3	31.9	33.4	34.2	32.4	33.0	33.5	33.2	32.0
	4	35.3	38.2	39.3	37.5	37.4	38.6	37.9	37.1
	5	35.9	36.2	37.8	36.9	36.6	37.0	36.8	35.8
	6	32.5	32.5	32.7	32.8	31.7	31.9	32.4	31.0
	7	35.0	37.5	37.7	36.4	37.3	36.8	36.9	35.2
	8	37.6	37.2	38.2	37.5	37.2	38.2	37.4	36.9
	9	31.0	32.6	32.5	32.8	32.4	32.4	32.4	33.6
	10	34.2	35.2	36.2	35.3	35.0	34.7	35.0	33.6
	11	37.9	37.0	37.0	36.7	37.0	36.9	37.1	37.0
	12	36.2	37.4	38.4	37.2	37.3	37.9	37.5	36.8
$\bar{X}$		34.27	35.96	36.58	35.51	35.53	35.84	35.73	34.70

TABLE H

EXERCISE SURFACE TEMPERATURES (^{o}C)

	S's	Abdomen	R.Scapula	Forehead	Chest	Deltoid	L.Scapula	Average	Up.Leg
	1	33.3	34.7	36.0	34.9	34.2	34.6	34.5	34.4
	2	37.1	38.0	39.7	37.6	38.8	38.3	38.3	37.7
	3	34.7	35.8	36.4	36.2	36.0	36.0	35.9	34.5
	4	36.2	38.1	39.7	38.0	37.5	38.6	38.1	37.5
	5	37.1	38.2	39.3	38.7	38.3	38.4	38.4	36.2
Trial 1	6	35.5	35.2	36.1	35.2	35.0	34.5	35.0	34.6
	7	34.9	36.8	37.6	35.9	36.3	36.3	36.2	34.1
	8	37.1	37.0	38.9	38.3	37.2	37.6	37.6	36.7
	9	32.3	32.4	32.5	32.7	31.5	32.5	32.2	31.2
	10	35.9	36.5	37.0	36.1	36.1	35.8	36.2	35.4
	11	40.2	40.6	40.7	40.6	40.8	40.0	40.5	39.6
	12	37.4	38.5	39.2	38.1	37.8	38.3	38.3	37.1
	1	36.4	37.8	38.9	38.5	38.0	37.7	37.9	37.8
	2	33.8	34.9	37.9	39.2	35.7	35.8	35.3	33.2
	3	34.2	35.5	36.2	35.9	35.3	35.7	35.5	33.6
	4	37.2	38.6	39.5	38.4	38.9	38.6	38.7	38.4
	5	35.4	36.3	37.9	36.8	36.9	36.6	36.7	34.9
Trial 2	6	37.5	36.9	38.9	37.4	37.1	37.2	37.4	36.4
	7	38.6	40.6	41.2	40.4	40.2	40.3	40.4	40.0
	8	36.9	38.5	39.3	39.0	38.3	37.0	38.3	37.9
	9	38.7	38.6	39.4	39.3	39.3	38.4	38.6	38.1
	10	34.7	34.4	35.4	34.5	34.2	34.7	34.8	32.9
	11	35.8	37.1	38.0	36.0	36.3	36.4	36.7	35.9
	12	32.1	34.7	36.5	35.1	34.2	34.2	34.6	32.5
	1	34.3	34.8	37.5	34.9	35.4	35.9	35.5	33.5
	2	29.9	33.2	35.1	33.2	31.6	33.5	32.8	30.8
	3	37.0	37.9	39.1	38.0	37.5	38.1	38.0	36.7
	4	36.0	38.3	39.3	37.6	37.7	38.0	38.1	37.4
	5	37.4	38.8	39.3	38.4	39.4	38.6	38.8	38.0
Trial 3	6	35.3	35.5	36.5	35.8	34.8	35.7	35.6	34.7
	7	37.3	39.0	40.0	39.4	39.2	38.8	39.0	38.6
	8	36.1	37.5	38.4	37.7	37.9	36.8	37.6	36.3
	9	37.8	39.0	39.4	38.9	38.2	38.9	38.6	37.9
	10	37.0	39.1	39.7	38.8	39.8	39.0	38.9	37.7
	11	36.6	36.3	37.4	37.2	36.0	37.2	36.9	34.8
	12	36.4	38.0	39.2	38.4	37.9	37.8	38.2	36.2
	1	40.4	39.8	40.8	41.1	40.6	40.0	40.5	39.6
	2	32.2	36.2	37.0	35.3	35.1	35.6	35.7	34.3
	3	35.6	37.2	38.0	37.4	36.7	37.0	37.0	34.8
	4	35.8	36.7	37.0	38.5	35.7	36.6	36.9	34.9
	5	33.4	34.6	35.8	35.2	35.8	35.6	35.2	32.8
Trial 4	6	35.0	34.9	35.2	35.2	34.3	34.7	34.9	33.9
	7	38.1	39.0	40.3	39.3	39.4	39.1	39.3	38.7
	8	37.3	39.2	39.8	39.3	39.2	38.4	38.9	39.0
	9	38.6	39.7	40.4	40.2	40.2	39.7	39.8	39.7
	10	34.6	35.7	36.3	35.6	35.5	35.6	35.6	35.1
	11	35.0	34.0	35.9	36.4	33.4	36.0	34.8	31.2
	12	43.2	44.5	45.4	45.3	45.4	44.9	44.9	43.3
$\bar{X}$		36.11	37.18	38.23	37.39	37.10	37.19	37.24	36.05

TABLE I

AVERAGE SURFACE TEMPERATURE DIFFERENCE SCORES (EXERCISE--PRE-EXERCISE) IN $^{\circ}$C

		Subject No.	25°	29°	33°	37°
450 kpm	50%	1	0.0	0.7	1.7	2.2
		2	0.3	1.3	1.3	2.3
	80%	3	-0.1	0.6	2.0	2.7
		4	0.8	0.2	2.9	3.1
750 kpm	50%	5	0.5	1.2	1.8	2.2
		6	1.6	0.9	1.5	2.6
	80%	7	-0.5	1.9	3.3	3.5
		8	0.2	0.7	1.8	3.9
1050 kpm	50%	9	-0.2	0.9	0.6	2.9
		10	0.4	1.2	1.5	2.1
	80%	11	0.0	1.7	3.5	3.4
		12	0.4	0.8	1.9	2.9

TABLE J

CHANGE IN UPPER LEG SURFACE TEMPERATURE ($^{\circ}$C) WITH EXERCISE

		Subject No.	25°	29°	33°	37°
450 kpm	50%	1	1.5	0.5	1.2	2.1
		2	-0.4	1.0	0.9	2.3
	80%	3	0.1	2.2	2.2	2.3
		4	0.1	0.4	2.7	3.9
750 kpm	50%	5	-0.6	0.1	0.4	2.6
		6	1.9	0.8	2.1	3.6
	80%	7	-1.1	0.7	2.1	4.0
		8	-0.2	1.4	1.1	3.8
1050 kpm	50%	9	0.0	1.7	0.7	2.0
		10	0.3	1.8	2.4	2.3
	80%	11	-1.4	1.5	4.7	2.6
		12	-0.7	0.3	1.1	2.1